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REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-OM-13

REMR MANAGEMENT SYSTEMS—NAVIGATION STRUCTURES

CONDITION RATING PROCEDURES FOR SECTOR GATES

by

Lowell Greimann, James Stecker, and Kevin Rens
Engineering Research Institute
Iowa State University
Ames, Iowa 50011

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HY	Hydraulics	OM	Operations Management
CO	Coastal		

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COVER PHOTOS:

TOP - The W.P. Franklin Lock and Dam, built in 1965 on the Caloosahatchee River near Olga, FL.

BOTTOM - The Algiers Lock, built in 1956 on the Gulf Intercoastal Waterway near New Orleans, LA.

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Iowa State University
Ames, IA 50011

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As part of the US Army Corps of Engineers' Repair, Evaluation, Maintenance, and Rehabilitation (REMR) program, the project team at Iowa State University (ISU) has focused on the evaluation and repair of the sector gate structures within the Corps civilian projects. This report includes a uniform procedure to describe the current condition of sector gate structures.

The entire inspection and rating process is based on a field inspection of the sector gate structure. During this inspection, current physical attributes of the systems are obtained. Pertinent data (gate location, inspection and maintenance histories, and historical water level) are recorded on an inspection form. The form also includes space for entering field measurements (anchorage movements, elevation changes, gate deflection, cracks, dents, and corrosion), which are used directly to rate the condition of the gate.

This information is used to calculate a condition index (CI), or numerical measure from 0 to 100, of the structure's current state. The index is meant to focus management attention on those structures most likely to warrant immediate repair or further evaluation, and can be used to monitor change in the general condition over time and to serve as an approximate comparison of the condition of different structures.

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PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Operations Management problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32280, "Development of Uniform Evaluation for Procedures/Condition Index for Deteriorated Structures and Equipment," for which Dr. Anthony M. Kao is the Principal Investigator. Mr. James E. Crews (CECW-O) is the REMR technical monitor for this work.

Mr. William N. Rushing (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE; Mr. James Crews and Dr. Tony C. Liu (CEEC-ED) serve as the REMR Overview Committee; Mr. William F. McCleese, US Army Engineer Waterways Experiment Station, is the REMR Program Manager; Dr. Kao is the Problem Area Leader for the Operations Management problem area.

This work was conducted by the US Army Construction Engineering Research Laboratories (USACERL) under the general supervision of Dr. Paul A. Howdyshell, Chief of the Engineering and Materials Division, Infrastructure Laboratory. The technical editor was Mr. William J. Wolfe, Information Management Office.

LTC David J. Rehbein was Commander of USACERL and Dr. L.R. Shaffer was Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees	0.0174533	radians
cubic ft (ft^3)	0.0283	cubic meters
square ft (ft^2)	0.093	square meters
feet	0.3048	meters
inches	25.4	millimeters

CONDITION RATING PROCEDURES FOR SECTOR GATES

PART I: INTRODUCTION

Background

1. Recently, the mission of the US Army Corps of Engineers has been shifting from the construction of new facilities to the maintenance of existing facilities because many existing structures are nearing the end of their design life and fewer opportunities for expansion of Corps projects are available. The Corps has addressed its changing role by instituting a Repair, Evaluation, Maintenance, and Rehabilitation (REMR) program. As a part of this program, the project team at Iowa State University (ISU) has focused on the evaluation and repair of the sector gate structures within the Corps' civilian projects.

Objectives and Scope

2. The objectives of this work are two-fold:

   a. To develop a uniform procedure to describe the current condition of sector gate structures

   b. To develop guidelines for the maintenance and repair of these structures. Only the first of these objectives is being addressed in this report.

Mode of Technology Transfer

3. It is recommended that the inspection procedures developed in this study for sector gates be incorporated into Engineer Regulation (ER) 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures."

Overview

4. The concepts and ideas presented here for the maintenance management of sector gates rely heavily on work in a similar project for steel sheet pile structures[1] and miter lock gate structures.[2] During that earlier work, basic ideas such as structural considerations, condition indexes, safety and serviceability, quantification of distresses by field measurements, limiting

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[1] Greimann, L., and Stecker., J. 1990. "Maintenance and Repair of Steel Sheet Pile Structures," Technical Report REMR-OM-9. U.S. Army Corps of Engineers, Washington, D.C.

[2] Greimann, L., Stecker, J., and Rens, K. 1990. "Management System for Miter Lock Gates," Technical Report REMR-OM-08. U.S. Army Corps of Engineers, Washington, D.C.

values of distresses, repair and maintenance alternatives, and others began to evolve. As these concepts were applied to sector gates, several enhancements and some new ideas have become apparent.

5. During the course of this project, the project team at ISU has met with Corps personnel and conducted site visits and field investigations at many lock facilities with sector gates. These meetings led to the identification of several basic considerations for sector gates. Corps experts conveyed their opinions as to the critical components of sector gate operation and repair, suggested means of quantifying these components, and related them to the overall condition of the sector gates. The project team took the experts' comments and formulated them into an inspection procedure and a tentative set of rating rules. Field tests of the inspection form and rating rules were conducted at four gate sets. At each test site, improvements to the rules and inspection process were suggested by the experts. Insofar as possible, the suggestions have been incorporated into this work except for cases of conflicting expert opinion.

Field Inspection

6. The inspection and rating procedure is illustrated schematically in Figure 1. The entire process is based on a field inspection of the sector gate structure. During this inspection, current physical attributes of the systems are obtained. Data, such as the location of the gate, inspection history, historical water level, and maintenance history, are recorded on the first two pages of the inspection form. Additional pages provide space for entering several field measurements such as anchorage movements, elevation changes, gate deflection, cracks, dents, and corrosion. These measurements are used directly to rate the condition of the gate.

Condition Index

7. The rating process is the next step. Information in the inspection data is used to calculate a condition index (CI) for the structure. A CI is a numerical measure of the current state of a structure. It is part of the goal of this project to define a CI that uniformly and consistently describes and ranks the condition of sector gate structures. The index is meant to focus management attention on those structures most likely to warrant immediate repair or further evaluation. In addition, the CI values can be used to monitor change in the general condition over time and can serve as an approximate comparison of the condition of different structures. The CI, a numbered scale from 0 to 100, indicates the relative need to perform REMR work because of deterioration of the general operating and structural characteristics of the structure (Table 1).*

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* Tables begin on page 62.

8. Two general structural criteria for evaluating the CI are available: safety and serviceability. Safety relates to the performance of a structure beyond normal service conditions, for example, under such abnormal conditions as excessive load. Serviceability relates to the performance of a structure under normal service conditions, for example, excessive leakage. The CI for each distress is based on field measurements of the distresses and the opinion of experts. It includes both safety and serviceability aspects. (Parts III and IV deal with the CI in more detail).

9. The overall CI is the weighted average of all the individual distress condition indexes. Hence, if the structure has a poor CI, the engineer is alerted and can trace the cause to a structural or routine maintenance problem.

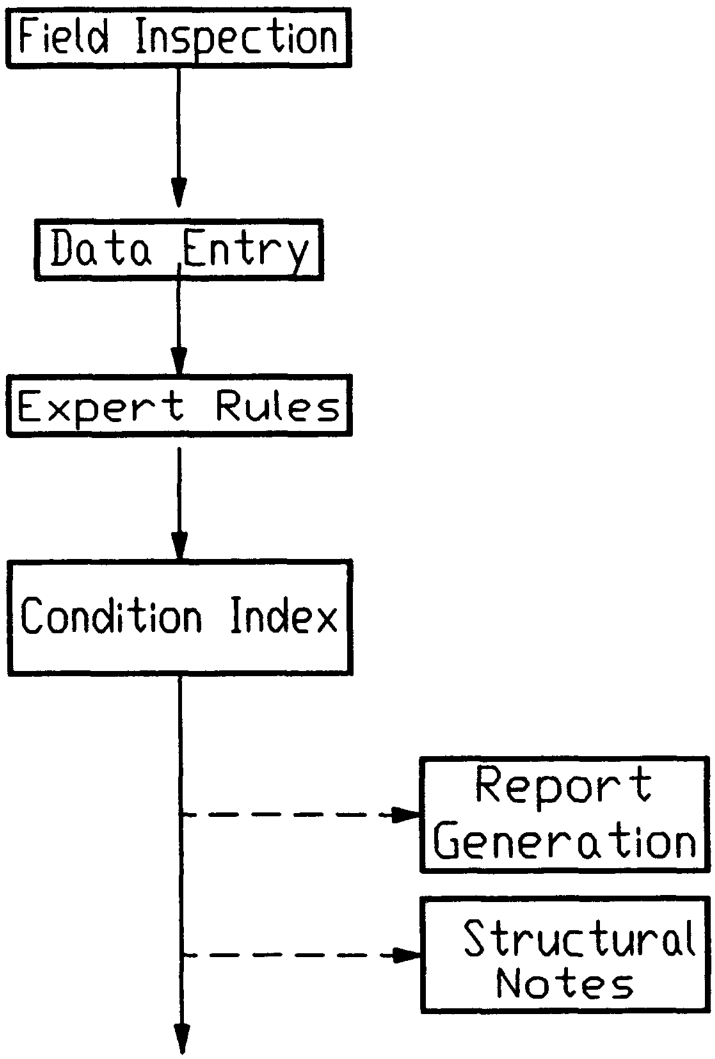


Figure 1. Inspection and rating procedure

Sector Gate Component Identification

10. To inspect and rate sector gate structures, the user must clearly identify the components; definitions for these components are presented below. Figure 2 illustrates a typical lock and dam facility.

Vertex: The point on the walkway directly above the pintle and hinge assemblies (Figure 3). The gate leaf pivots around this point.

Nose: The point on the gate leaf walkway where contact is made with the adjacent gate in the closed position (Figure 3).

Recess: The point opposite the nose (Figure 3). Note: Vertex, nose, and recess are simply reference points at the walkway elevation.

Skin Plate: The plate welded to the vertical ribs to dam the water and provide stiffness to the structure (Figure 4).

Vertical Ribs: Usually consisting of angles or tees that transfer load from the skin plate to the horizontal girders (Figure 4). They usually have a minimum depth of 8 in. to facilitate painting and maintenance.

Horizontal Girders: Usually 24 in. deep and designed to withstand a combined water and boat load (Figure 4). They are curved to conform to the circular arc of the sector gate and transfer load from the ribs to the internal framework.

Framing: The internal framework consisting of vertical and horizontal trusses that transfer load from the horizontal girders to the vertex of the gate (Figure 4). Some members are common to both sets of trusses and the specific arrangement of members varies from gate to gate.

Hinge Assembly: Supports the top of the gate leaf and transfers horizontal load into the concrete wall (Figure 5). The assembly consists of a hinge bracket (or hinge pin housing), a hinge pin, and a bracket support. The hinge bracket is a cast steel section that houses a bushing and the hinge pin. This allows the gate leaf to pivot. Slotted bolt holes and shims are sometimes used to adjust the gate horizontally as needed. The bracket support is a cast steel plate connected to the wall by anchor bolts. In some instances more than one assembly is used to support the gate.

Pipe Column: A cylindrical column that runs from the hinge bracket to the pintle assembly (Figure 6). The purpose is to transfer vertical load to the pintle assembly.

Pintle Assembly: Generally located at the bottom of the vertex of the gate leaf (Figure 6) and transfers vertical load from the gate leaf into the foundation. The pintle itself is usually made of stainless steel to resist corrosion. Two pintle types have been observed, one being a straight pin and the second a partial sphere. The spherically shaped pintle allows slight tipping without binding. The cylindrical shaped

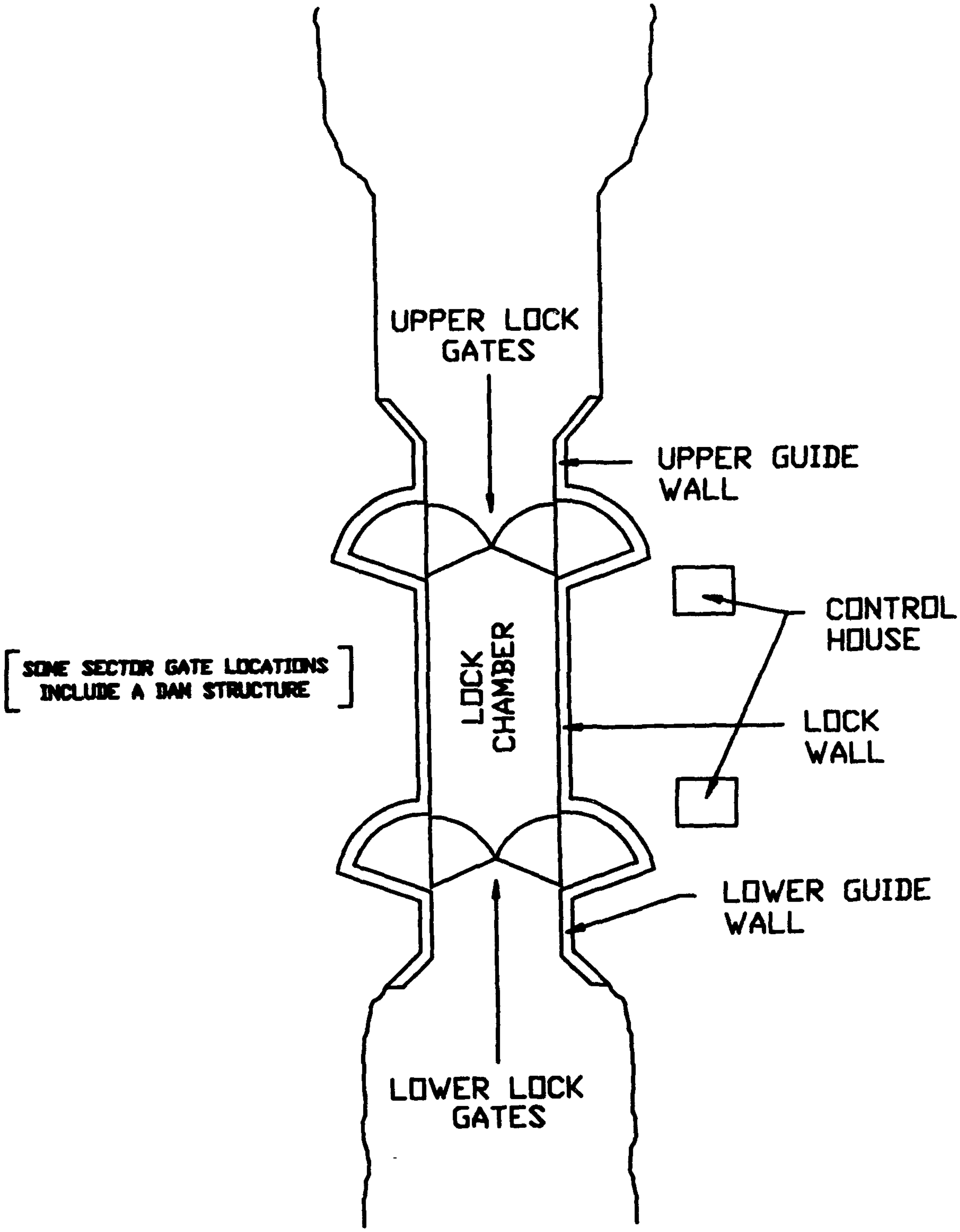


Figure 2. Lock and dam facility

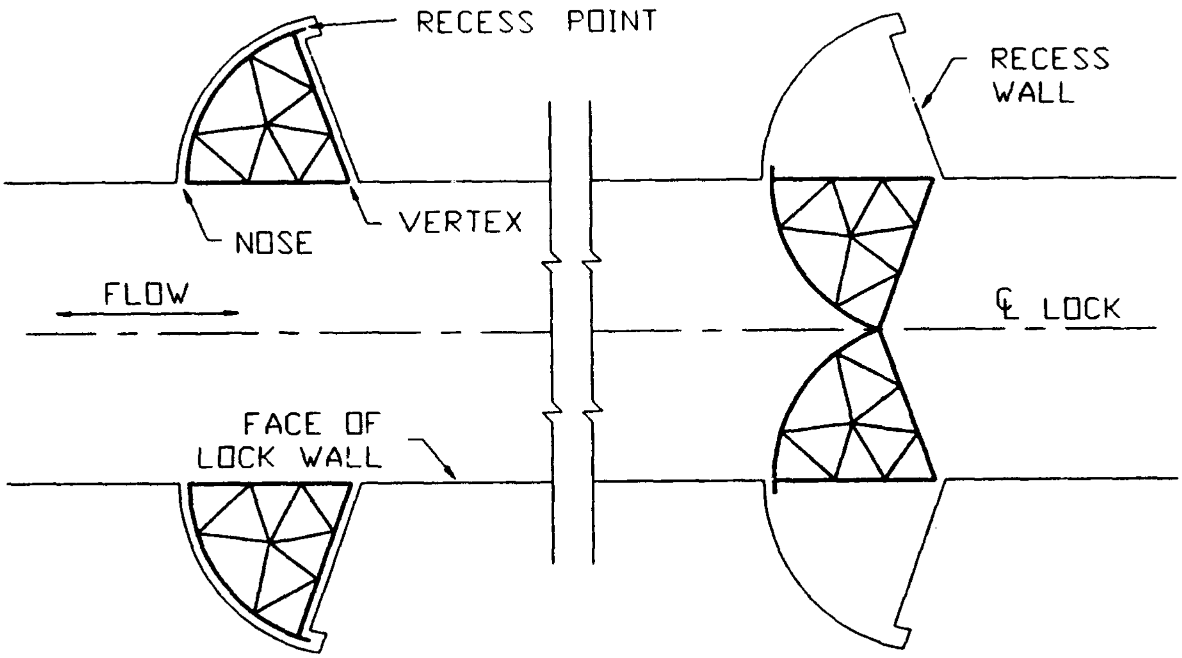


Figure 3. Sector gate chamber

bottom portion of the pintle fits into a recess in the pintle base and bears directly on the base. In some cases the pintle is located at the top of the vertex, above the hinge assembly. Support girders extend from the gate leaf into a housing above the gate leaf. This housing contains the pintle assembly and supports the vertical load of the gate leaf.

Pintle Bushing: A bronze bushing that encases the spherical portion of the pintle (Figure 6). It is connected to the pintle housing so that movement between the two is eliminated.

Pintle Housing: A cast steel section that transfers load from the internal framing into the pintle (Figure 6). It fits over the top of the pintle bushing and connects the various structural components that pass through that point.

Pintle Base: A cast steel section that encases the cylindrical portion of the pintle (Figure 6). It is anchored to the foundation for transferring load into the concrete.

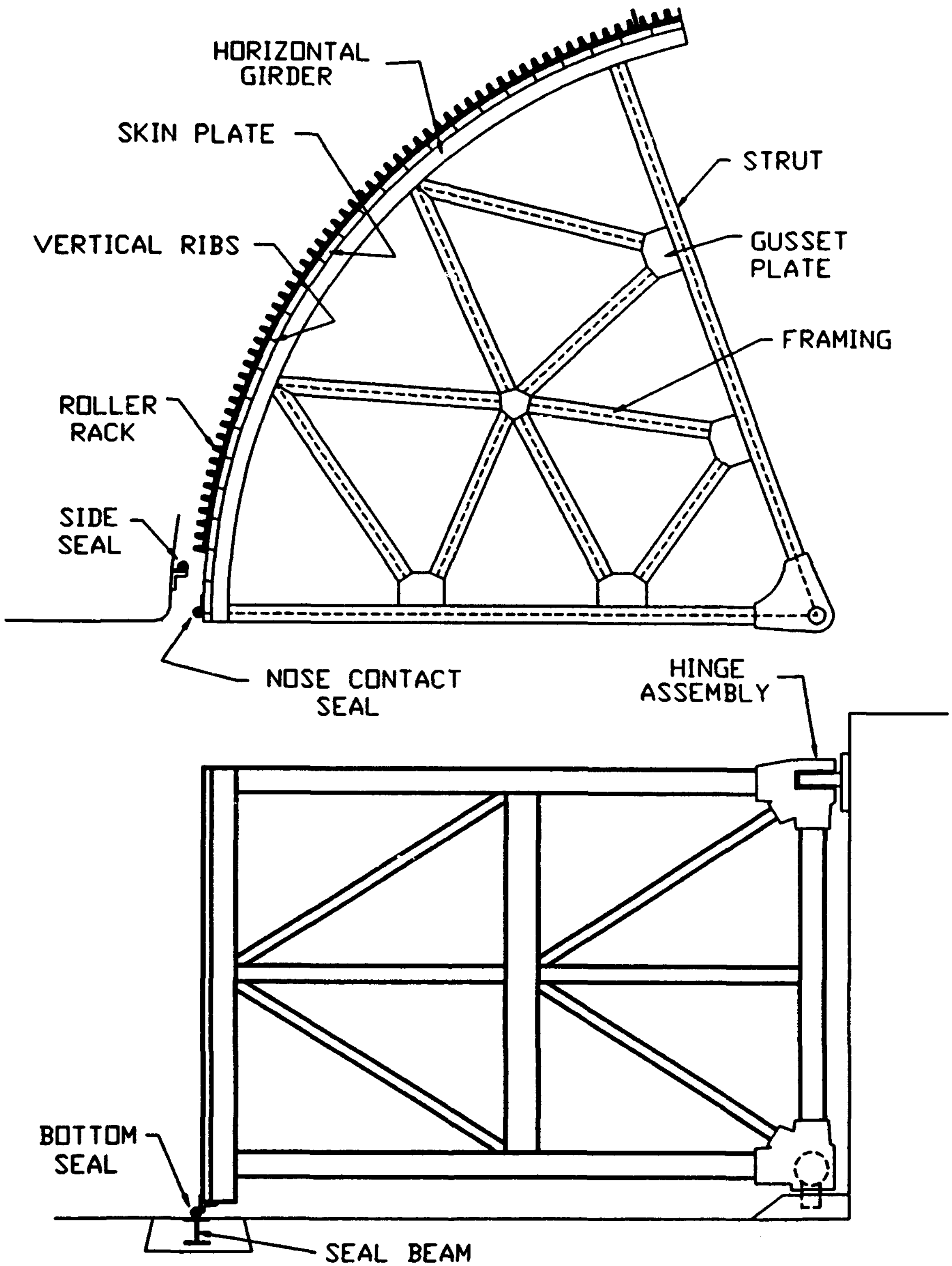


Figure 4. Sector gate

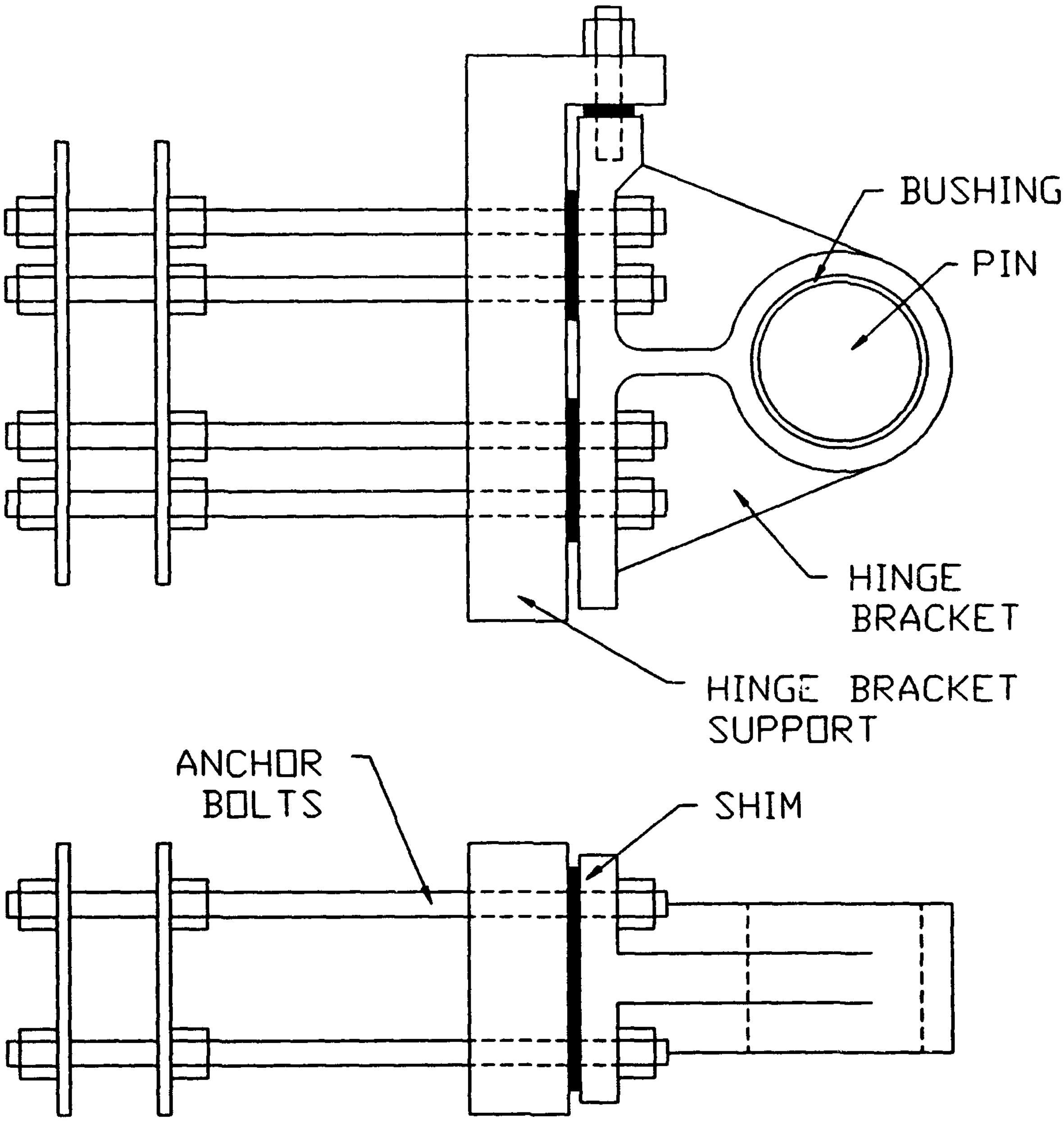


Figure 5. Anchorage configuration

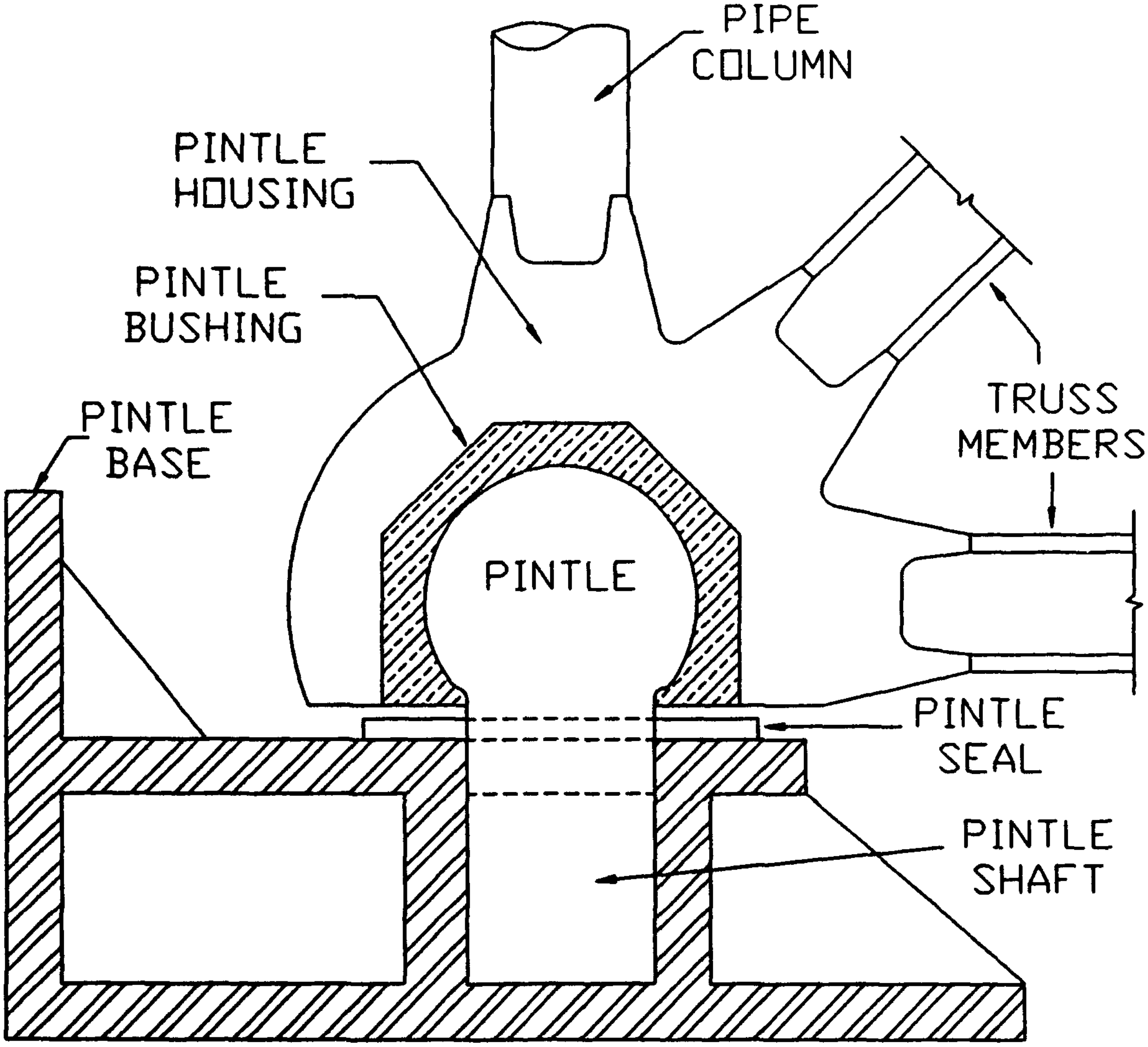


Figure 6. Pintle configuration

Seals: Vertical seals are used at the nose and the recess points, and a horizontal seal is used between the bottom of the gate leaf and the floor of the lock chamber (Figure 4). J-seals are most common, but various other types are used.

Operating Machinery: Sector gates are generally controlled in one of three different ways. The first type uses a rack and pinion system and the second type replaces the rack and pinion with a cable and drum arrangement that pulls the gate in and out of recess. The third type uses a hydraulic strut arm and is not common.

PART II: FIELD INSPECTION

11. The field inspection is based on data that are easily obtainable from the top of the gate or the lock wall, or from a boat in the lock chamber. The normal inspection involves no underwater diving nor ultrasonic or other sophisticated devices. All data are measured by subjective observation, a tape measure, a level, a ruler, dial gauges, a camera, and the like. Data will be collected from the gate with the lock in an operating mode, that is, not dewatered. Minimal disturbance to lock traffic was a requirement.

12. The inspection process generally follows this pattern:

a. Historical information, such as drawings and previous inspections, is reviewed and recorded before a site visit.

b. A site inspection is conducted and specific visual data are recorded.

c. The inspection data are entered into a personal computer program.

Overview of the Inspection Form

13. The inspection form (on the following pages) has been designed to provide flexibility in documenting a variety of field conditions within one standard form. Though there are four pages in the inspection form, data for the first two can be entered prior to the initial inspection. The following paragraphs briefly outline the inspection form.

Historical Information

14. Historical information related to the sector gate structure is recorded on pages 1 and 2 of the inspection form. Information includes project reference data to identify and locate the specific structure. Further data categorize the structure into a particular type and function. The information is also used to sort through the expert rules in the evaluation model. The recent history of maintenance, modifications, inspections, and the like is recorded. Finally, a section to record present-day physical conditions of sector gate accessories is also provided.

Field Measurements

15. Pages 3 and 4 of the inspection form are for recording measurements made in the field. Several measurements are requested, such as anchorage movements, gate deflections, elevations, dents, cracks, noises, leaks, and corrosion levels. All of these field measurements are used with the expert rules described in Part III to determine the CI for the gates.

16. Some measurements on these pages are made at four different gate positions:

a. Recessed: The leaf is completely open.

b. Jacked: The gates are brought to a half-closed or recessed position and hydraulic jacks relieve the anchorage system of load.

c. Closed, 1-ft head: The gates are brought to fully closed position and a nominal 1-ft of head is placed on the gates. The small head closes some gaps and stabilizes the gate during the measurement process.

d. Closed, full head: Full hydraulic head is applied to the gate.

17. Jacking of the gate leaves is required at least once for a complete CI evaluation of a set of sector gate leaves. Three possible jacking scenario combinations exist during an inspection:

a. Gate leaves are jacked during the current inspection. The evaluation of the CI for certain individual distresses depends on measurements in all gate positions (a, b, c, and d). The combined CI will be most current for this scenario because all information will be current.

b. Gate leaves are not jacked during current inspection, but previous jacking information exists. The CI evaluation for certain individual positions (a, c, and d) in the current inspection data and information from previous inspections for the jacked data (position b). The combined CI is evaluated for this scenario but is partially based on measurements from scenario (a).

c. Gate leaves have not been jacked and will not be jacked during current inspection. Certain individual condition indexes cannot be calculated. The combined CI will not be calculated.

General Notes for Inspection

18. Figure 7 shows the actual inspection form with entries from an actual test inspection. Data for supplemental page 3 were not available. The side-by-side arrangement of the following pages displays specific explanations adjacent to the entry on the inspection form. Pages 3 and 4 of the inspection form also have notes on how to measure and record critical data.

19. A suggested sequence of data collection for pages 3 and 4 for two sets of sector gate leaves is shown in Figure A-1 in the Appendix. At least a three-person team is required--two on top of the lockwalls and one in the boat starting above the upper gate. The two people on top should independently read and record measurements and elevation readings. Verify data before proceeding to the next step. This may eliminate data errors.

NAME OF CIVIL WORKS PROJECT

____
____

LOCATION OF CIVIL WORKS PROJECT: (1. Body of water, 2. Nearest town)
1. ____________________________________
2. ____________________________________

INSPECTION DATE: ____________ INSPECTED BY: ____________

ARE THE GATE LEAVES GOING TO BE JACKED DURING THIS INSPECTION? (Y/N)

GATE FUNCTION:

1. Lock gate
2. Flood gate

GATE FUNCTION (No.) ________

GATE IDENTIFICATION (LOCK GATES ONLY):

1. Upper gate
2. Lower gate

GATE ID (No.) ________

TYPE OF CLOSING MECHANISM:

1. Gear
2. Strut
3. Cable

CLOSING MECH (No.) ________

TYPE OF SKIN PLATE:

1. Single
2. Double

SKIN TYPE (No.) ________

ARE GATE LEAVES SUPPORTED ON SILL BY ROLLERS? (Y/N) ________

LENGTH OF LOCK CHAMBER (LOCK GATES ONLY): (ft) ________

WIDTH OF LOCK CHAMBER: (ft) ________

HEIGHT OF GATE LEAF: (ft) ________

GATE WIDTH: (ft) ________

SALT OR FRESH WATER? (S/F) ________

PRESENT WATER LEVEL: (ft) UPPER POOL _____ LOWER POOL _____

RECORD LOW WATER LEVEL: (ft) UPPER POOL _____ LOWER POOL _____

RECORD HIGH WATER LEVEL: (ft) UPPER POOL _____ LOWER POOL _____

DO YOU ROUTINELY DEWATER THE LOCK CHAMBER? (Y/N) _____ IF YES, WHAT YEAR WAS THE LOCK LAST DEWATERED? ______ INTERVAL PERIOD ______

CONSTRUCTION DATE: ____________

Figure 7. Inspection form (Sheet 1 of 4)

Page 1 comments: Historical or record keeping data

Completed prior to the site inspection and verified or changed during the site inspection.

Data blanks on page 1 prefaced by (No.) ___ must be recorded as numbers.

Enter the Corps of Engineer Project Title in NAME.

Indicate the BODY OF WATER. This may be a river, canal or improved channel, lake, or coastline.

Indicate whether or not jacking will be performed during this inspection.

Indicate GATE FUNCTION, GATE IDENTIFICATION, TYPE OF CLOSING MECHANISM, and TYPE OF SKIN PLATE by entering the appropriate number in the blank following each name. Refer to the section called "Sector Gate Component Identification" for descriptions and illustrative figures if additional information is required.

Indicate if the gate leaves are supported on the sill by rollers.

Enter nominal LENGTH and WIDTH if lock chamber (e.g., 600 ft, 1200 ft, etc.)

Enter nominal WIDTH and HEIGHT of gate leaves.

Indicate whether this is a SALT water or a FRESH water structure. A salt water/fresh water interface is considered as a salt water environment.

Water level gauge readings referenced to mean sea level. PRESENT and RECORD LOW and HIGH WATER LEVELS are for reference.

Lock chamber dewatering periods and construction information may be important for reference.

ARE ORIGINAL GATE LEAVES CURRENTLY IN PLACE? (Y/N) ____________

IF NOT, IDENTIFY CURRENT GATE LEAF HISTORY: ____________________________

____

____

____

ARE DRAWINGS AVAILABLE FOR GATE LEAVES IN PLACE? (Y/N) ____________

ARE THE DRAWINGS INCLUDED WITH THIS FILE? (Y/N) ____________

PAST HISTORY

MAJOR MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS

	DATE	DESCRIPTION
(1):	________	______________________________
(2):	________	______________________________
(3):	________	______________________________
(4):	________	______________________________

PREVIOUS INSPECTIONS OR STRUCTURAL REVIEWS (attach copies if available)

	DATE	DESCRIPTION
(1):	________	______________________________
(2):	________	______________________________
(3):	________	______________________________
(4):	________	______________________________

TYPE OF FENDER PROTECTION AND CONDITION OF FENDERS:

____

____

____

____

TYPE OF WALKWAY ON GATE LEAF AND CONDITION OF WALKWAY:

____

____

OTHER COMMENTS:

____

____

____

____

____

____

Figure 7. Inspection form (Sheet 2 of 4)

Page 2 comments: Historical or General Data.

Completed prior to the site inspection and verified or changed during the site inspection.

Gate leaves are sometimes replaced or removed during rehabilitation. It is important for later reference to record the history of the in-place gate.

Dates and descriptions are entered on one line as one record. Record major MAINTENANCE, REPAIRS, OR OTHER MODIFICATIONS performed on the structure within the last 10 years.

Record present day type (steel or timber) and condition of FENDER protection.

Record present day type and condition of WALKWAY and hand rails on gate leaf. The items noted in this section are for information only and do not affect the CI rating of the structure. They are recorded in the inspection file for reference and so changes can be observed.

FACING DOWNSTREAM, IDENTIFY LEFT AND RIGHT LEAF AS N,S,E,W
LEFT GATE LEAF (LG) = ____________
RIGHT GATE LEAF (RG) = ____________

OPENING AND CLOSING OF GATE LEAVES

	LEFT	% CLOSED	Due to Op Mach, Seals	RIGHT	% CLOSED	Due to Op Mach, Seals
LEAF JUMPING	Y or N	____	Y or N	Y or N	____	Y or N
LEAF NOISE	Y or N	____	Y or N	Y or N	____	Y or N
LEAF VIBRATION	Y or N	____	Y or N	Y or N	____	Y or N

GATE VIBRATION UNDER FULL HEAD LEFT LEAF: Y or N RIGHT LEAF: Y or N

DEFLECTION OF GATE DURING OPERATION (in.)

	CLOSING	OPENING
LEFT LEAF	____	____
RIGHT LEAF	____	____

ELEVATIONS OF GATE LEAF (ft)
REFERENCE ELEVATION: LEFT LEAF ____________ RIGHT LEAF ____________

LEFT LEAF	RECESSED	CLOSED 1'HEAD	CLOSED* FULL HEAD
NOSE (N)	____	____	____
VERTEX (V)	____	____	____
RECESS (R)	____	____	____
RIGHT LEAF			
NOSE (N)	____	____	____
VERTEX (V)	____	____	____
RECESS (R)	____	____	____

ANCHORAGE SYSTEM MEASUREMENT (CONCRETE INTERFACE)

IS THE EMBEDDED ANCHORAGE FLEXIBLE OR RIGID? (F/R)
IF FLEXIBLE, LENGTH OF EMBEDDED ANCHORAGE (in.): ____________

SPALLED/CRACKED CONCRETE		ANCHOR CORROSION (Level 3 or greater)	
LEFT LEAF	RIGHT LEAF	LEFT LEAF	RIGHT LEAF
(Y/N)	(Y/N)	(Y/N)	(Y/N)

LEFT LEAF DIM. (in.)	RECESSED	CLOSED 1'HEAD	CLOSED* FULL HEAD	JACKED
CONCRETE PARALLEL	____	____	____	____
CONCRETE PERPENDICULAR	____	____	____	____

RIGHT LEAF DIM. (in.)	RECESSED	CLOSED 1'HEAD	CLOSED* FULL HEAD	JACKED
CONCRETE PARALLEL	____	____	____	____
CONCRETE PERPENDICULAR	____	____	____	____

HINGE PIN MEASUREMENT (GATES HALF OPEN)

		HANGING	JACKED
ANCHOR BRACKET TO PIN BRACKET (IN.)	LEFT LEAF	____	____
	RIGHT LEAF	____	____

* LOCK GATES ONLY

Figure 7. Inspection form (Sheet 3 of 4)

Page 3 Comments: Field data-Completed at site inspection.

Record the orientation of the lock chamber by facing downstream and identifying the left and right leaf as N, S, E, or W.

OPENING AND CLOSING OF GATE LEAVES: Observing the gate leaves during operation (opening and closing) is a good indicator of problems. If the gate leaf vibrates (chatters), indicate the approximate positions at which the noise or vibration occurs. Similarly, record the occurrence and positions of any unusual noises or jumping movement and indicate whether any noise, jump, or vibration is due to the operating machinery or the gate leaf seals.

LOCK CHAMBER FULL: When the chamber is full, water passing underneath the gate leaves may cause the seals to flutter (vibrate). Placing your ear near the walkway railing will amplify this noise as the gate leaf vibrates.

DEFLECTION: Record the horizontal deflection of the gate leaf as it is opening and closing. The purpose of this measurement is to record the movement of Point B (Figure 8) the instant rotation begins at the upper hinge pin at Point A. For the deflection during opening, a straight edge is clamped to the nose of the gate leaf at Point B. The straight edge cantilevers over a ruler laid on the lock wall.

The instant when Point A begins to rotate is somewhat imprecise and difficult to detect. One method that has been successful in field tests is illustrated schematically in Figure 8. Another straight edge is clamped to the gate leaf at Point A. This straight edge bears on a dial indicator that is connected to the lock wall, for example, to the hand rail. One inspector observes the dial indicator as the gate is *being opened. He/she* yells at the instant the dial starts to move. At that instant, the inspector at Point B observes the reading on the ruler. The DEFLECTION is obtained by subtracting the initial ruler reading from the instantaneous reading and is entered on the inspection form. Deflection can be measured to the nearest 1/8 inch. The decimal equivalent is entered into the computer. For the deflection during closing, Point B is located at the gate leaf's recess location.

ELEVATIONS OF GATE LEAVES: Establish a fixed reference point on the left and right concrete monolith. Record the reference elevation (height of instrument). When the gate leaves are in the recessed position (1), measure the nose, recess, and vertex elevations of each leaf. A specific point should be identified and marked at each of the three locations, usually on the walkway, near the nose, vertex, and recess. Measurement should be made with a rod and level. Repeat this process for two additional positions: (2) closed with one foot of head, and (3) closed with full head (lock gates only). Measurement should be recorded to nearest 0.005 foot, e.g., 1.115.

ANCHORAGE SYSTEM MEASUREMENT (Figure 9): Flexible anchorages are usually coated by an asphalt impregnated cork lining. Rigid anchorages rely partially on concrete bond as a support. The length of the embedded anchorage is measured from the hinge bracket support (Figure 10). Indicate the presence of excessive concrete cracking where the anchorage enters the concrete (Figure 10). Excessive concrete spalling may indicate that a displacement occurred at this location at some point in time and may or may not show up at a current measurement. Small hairline cracks, probably caused by thermal expansion or contraction of the concrete, should be ignored in this analysis. If the corrosion at any point in the anchorage system is level 3 or greater, record a Yes.

Measurements must be made on the anchorage arms with the leaf at four positions: (1) recessed, (2) closed with one foot of head, (3) closed with full head (lock gates only), and (4) jacked while half open or recessed. The concrete parallel and perpendicular locations can be measured with a dial gauge attached to a magnet or with dial gauges attached to bars. The perpendicular measurement is shown with a dial gauge attached to the anchor bracket as shown in Figure 9. The parallel measurement is also shown with a dial gauge attached to the magnet, but the plunger is measuring the parallel movement. Displacements should be recorded to 0.001 inch. If jacking is not performed during this inspection, enter NA in the jacked column.

HINGE PIN MEASUREMENT: The hinge pin measurement is the distance between the two reference Points A and B in Figure 11. The measurement is taken with the gates in the hanging and jacked position and recorded to the nearest 1/16 inch. Point A is a permanent reference point that is established on the hinge pin bracket and Point B is permanently established at the center of the hinge pin. Sometimes the permanent location of Point A lies at some distance below Point B. In this situation, Point A could be projected vertically upward with clamps and metal straps. The distance between the permanent reference points can be determined by calipers (Figure 11) or trammel points. (See Hinge Pin discussion in Part III.) If jacking is not performed during this inspection, enter NA in the jacked column.

OBSERVATIONS FROM BOAT

CORROSION AT WORST LOCATION (LEVEL 0,1,2,3,4, or 5)

	LEFT LEAF	RIGHT LEAF
UPSTREAM SKIN:	____	____
DOWNSTREAM SKIN:	____	____
GIRDER:	____	____
FRAMING:	____	____

DENTS -- SKIN PLATE (S), GIRDERS (G), OR FRAMING (F)

	LEAF	COMPONENT	LOCATION: DISTANCE FROM		SIZE (FT)	
	L OR R	S,G, OR F	TOP GIRDER (FT)	NOSE (FT)	HEIGHT	WIDTH
(1):	____	____	____	____	____	____
(2):	____	____	____	____	____	____
(3):	____	____	____	____	____	____
(4):	____	____	____	____	____	____
(5):	____	____	____	____	____	____

CRACKS -- SKIN PLATE (S), GIRDERS (G), OR FRAMING (F)

	LEAF	COMPONENT	LOCATION: DISTANCE FROM		SIZE
	L OR R	S,G, OR F	TOP GIRDER (FT)	NOSE (FT)	LENGTH (FT)
(1):	____	____	____	____	____
(2):	____	____	____	____	____
(3):	____	____	____	____	____
(4):	____	____	____	____	____
(5):	____	____	____	____	____

NOSE AND RECESS LEAKS @ LEFT RECESS (L), NOSE (N) or RIGHT RECESS (R)

TYPE-- L,N,R	DISTANCE FROM TOP	LENGTH (FT)	WIDTH (IN.)	DUE TO DAMAGED SEALS (Y/N)
(1): ____	____	____	____	____
(2): ____	____	____	____	____
(3): ____	____	____	____	____
(4): ____	____	____	____	____
(5): ____	____	____	____	____

SKIN LEAKS @ LEFT GATE (L), OR RIGHT GATE (R)

	LEAF	TYPE	SHORTEST DISTANCE FROM		AREA	
	L OR R	(H)ORIZ. OR (V)ERT	TOP GIRDER (FT)	WALL (FT)	LENGTH (FT)	WIDTH (IN.)
(1):	____	____	____	____	____	____
(2):	____	____	____	____	____	____
(3):	____	____	____	____	____	____
(4):	____	____	____	____	____	____
(5):	____	____	____	____	____	____

SILL BOILS @ LEFT GATE (L), RIGHT GATE (R), NOSE (N)

	TYPE (L,R, OR N)	DISTANCE FROM NOSE (FT)
(1):	____	____
(2):	____	____
(3):	____	____
(4):	____	____
(5):	____	____

Figure 7. Inspection form (Sheet 4 of 4)

Page 3 Comments: Field Data.

CORROSION AT WORST LOCATION: The corrosion of the skin plate, girders, and framing is rated in a visual, subjective manner. Refer to Part III for more details on the rating scheme. Selection of the corrosion level at the worst location (generally the air/water interface) is made by comparing the observed condition to the standards in Table 2 and/or visually comparing it to the photographs in Figure 12. There are five levels of deterioration. Level 0 is new or nearly equal to new. Upstream and downstream levels are recorded for the skin plate.

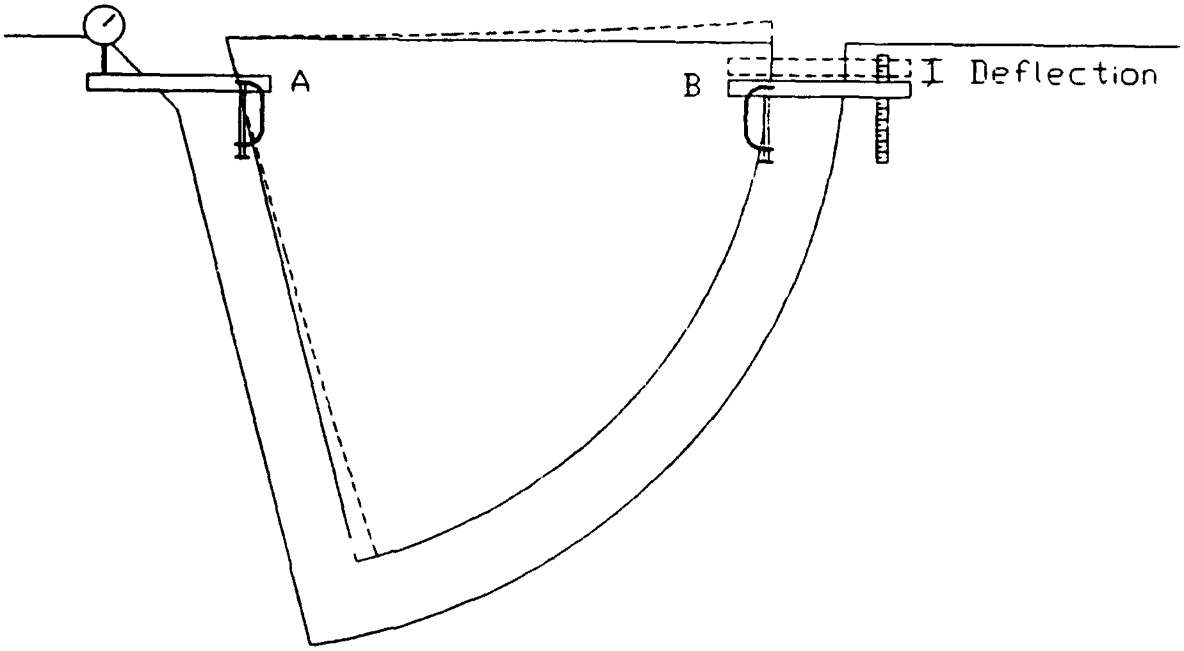
DENTS: The location and dimension of skin plate, framing, and girder dents are determined by a ruler or tape measure. The coordinates of the dent are taken as the distance from the top girder and nose.

CRACKS: The location and length of skin plate, framing, and girder cracks are made with a ruler or tape measure. The coordinates of the crack are taken as the distance from the top girder and nose to the nearest point of the crack.

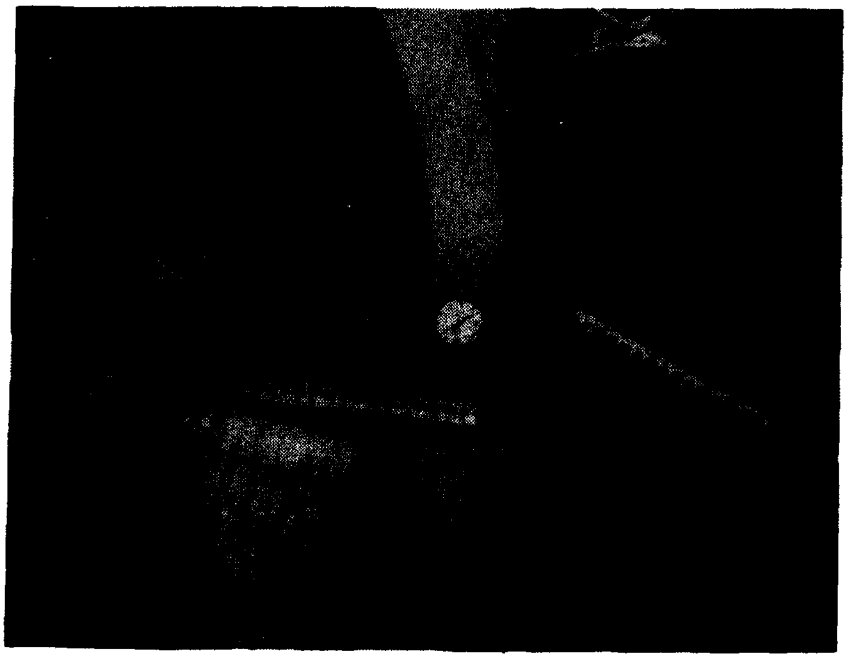
NOSE AND RECESS LEAKS: The location and length of the left recess (L), right recess (R), or nose (N), leaks are measured with a tape measure. The location of the leak is determined as the distance from the top girder to the top of the leak. A leak of zero length and zero width of zero indicates a point or local leak.

SKIN LEAKS: The location and dimension of skin plate leaks are measured by a tape measure. Two types of skin plate leaks usually exist: horizontal (H) indicates a horizontal leak and vertical (V) indicates a vertical leak. The coordinates of the leak are taken as the distance from the top girder and nose to the top of the leak. The length and width of the leak is also recorded.

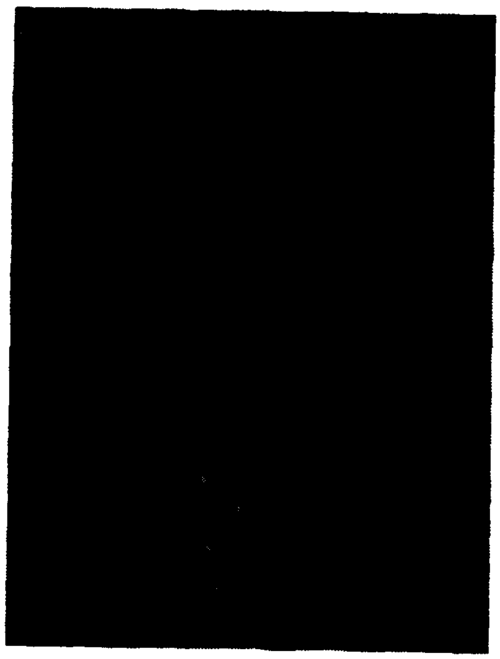
BOILS: The existence of boils from below the water surface on the right leaf (R) or left leaf (L) will be noted by location (distance from the nose). Nose boils are identified by an N with a zero distance.



(a) Plan view

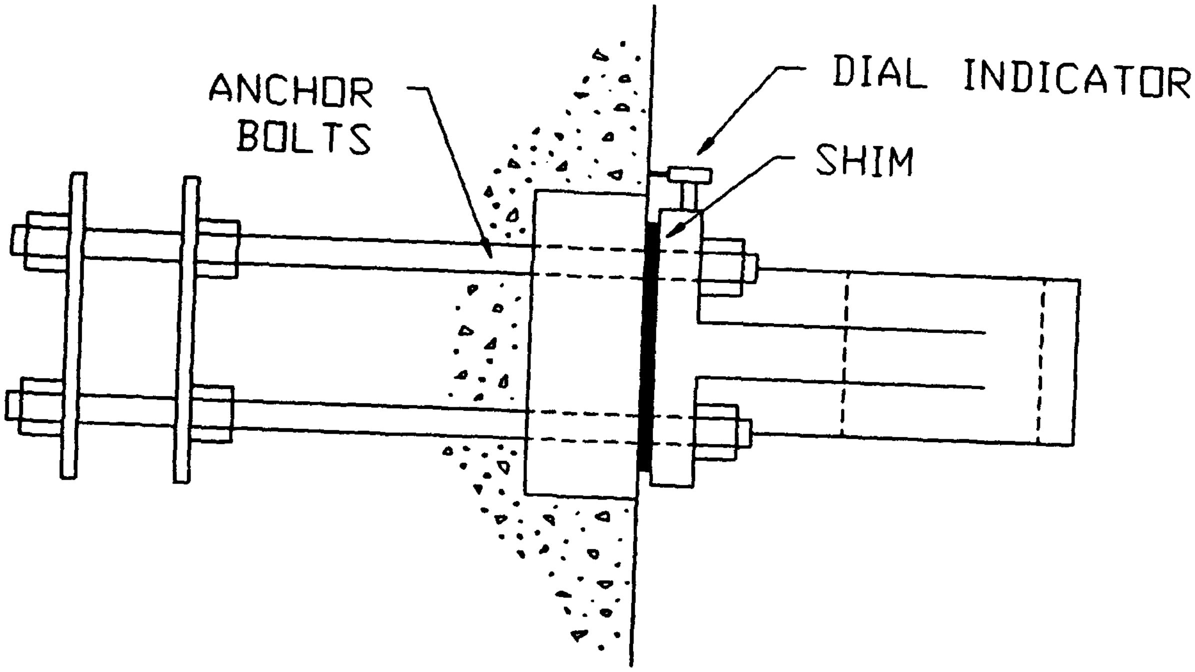


(b) Location A



(c) Location B

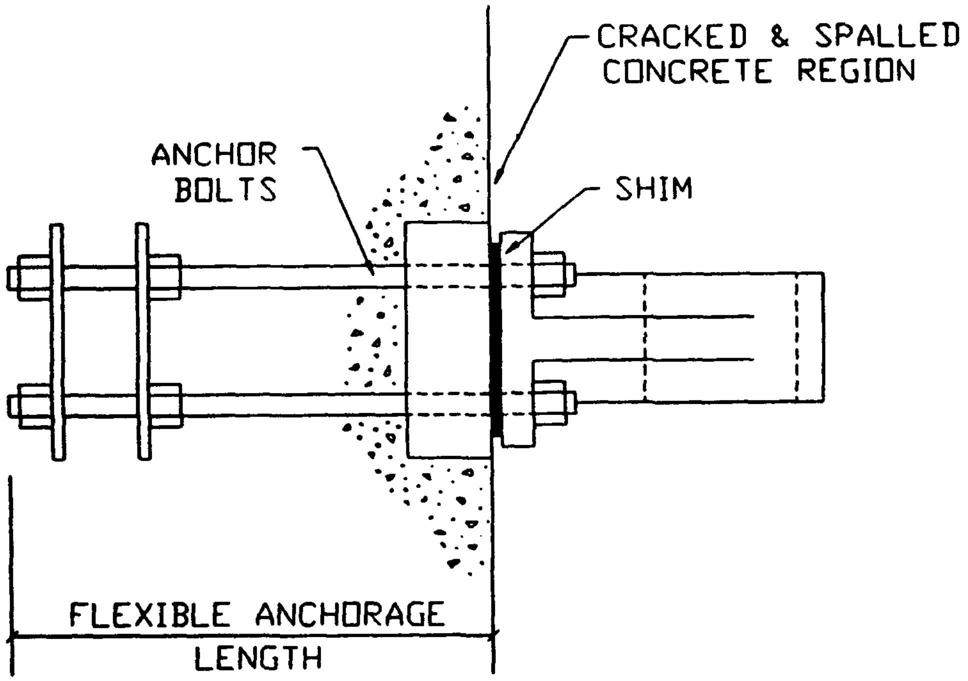
Figure 8. Gate deflection



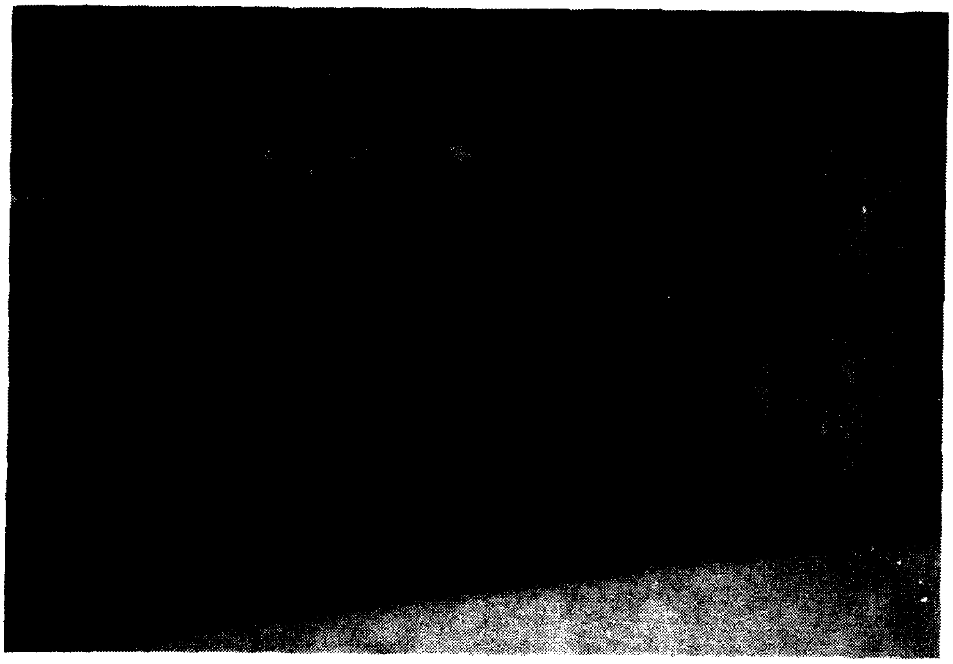
(a) Side view

(b) Parallel and perpendicular measurement

Figure 9. Anchorage measurement

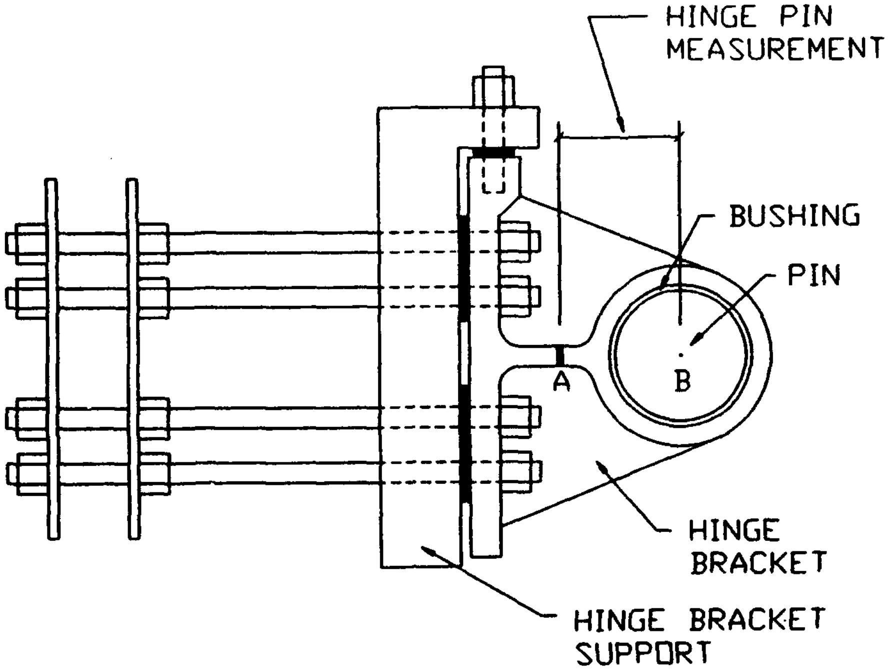


(a) Side view

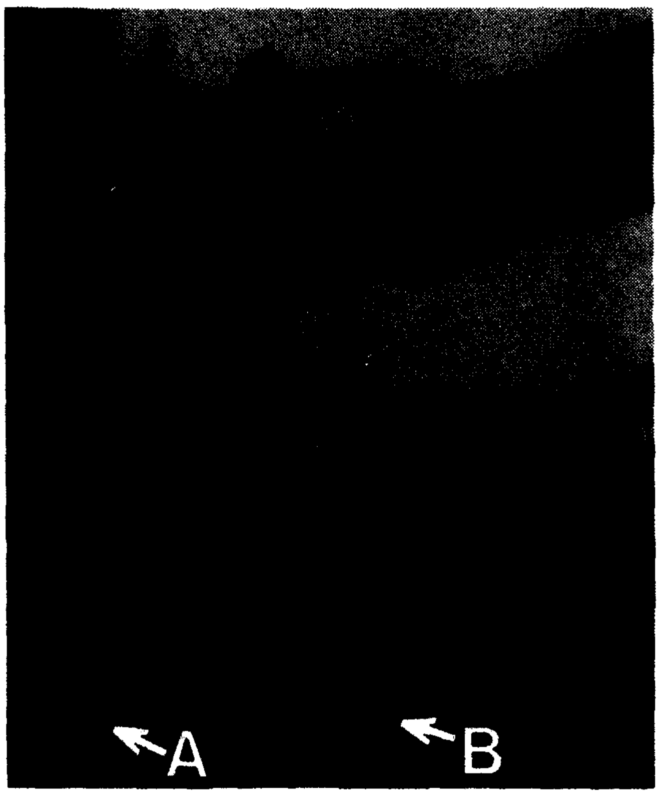


(b) Cracked and spalled concrete region

Figure 10. Anchorage



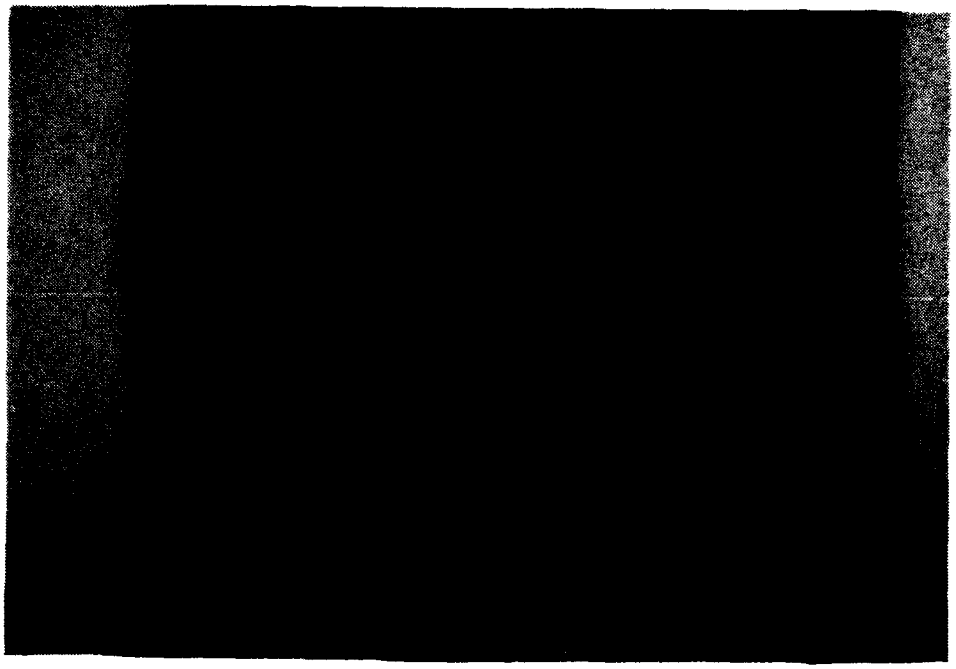
(a) Plan view



(b) Side view closeup (using calipers)

(c) Side view (using calipers)

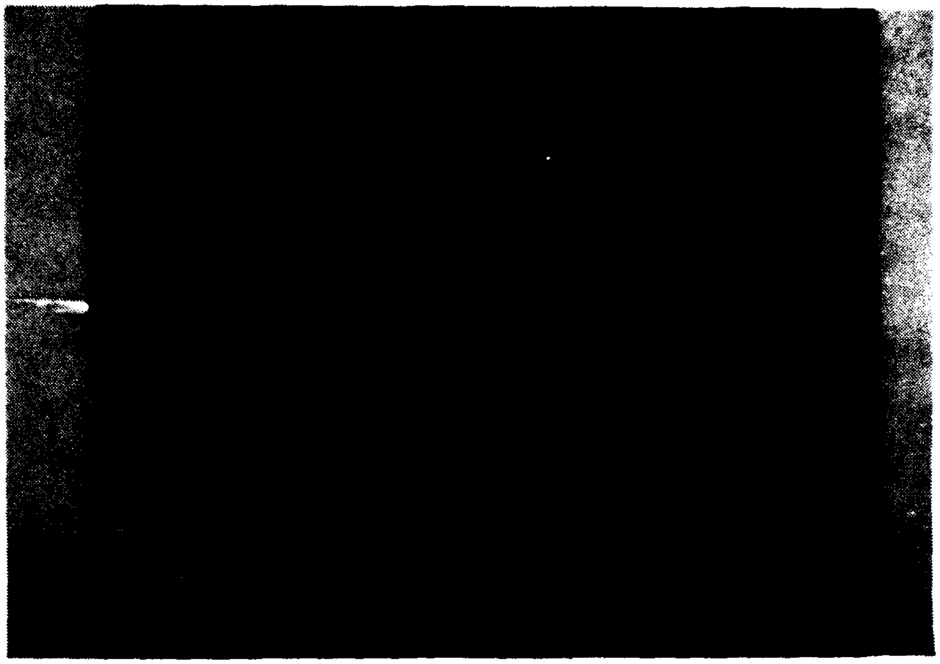
Figure 11. Hinge wear



(a) Level 1: Minor surface scale or widely scattered small pits

(b) Level 2: Considerable surface scale or moderate pitting

Figure 12. Levels of corrosion (Sheet 1 of 3)



(c) Level 3: Severe pitting in dense pattern and thickness reduction in local areas

(d) Level 4: Obvious uniform thickness reduction

Figure 12. (Sheet 2 of 3)

(e) Level 5: Holes due to thickness reduction and general thickness reduction

Figure 12. (Sheet 3 of 3)

PART III: CONDITION INDEX

20. Because the CI involves engineering judgment and depends on the experience of the person making the evaluation, these aspects of the CI were difficult to capture. Experts in this field were interviewed and discussion continued over more than 1 year until a consensus began to develop. The authors have attempted to blend all the opinions expressed at these meetings into a set of "expert opinion" rules that are embedded in the evaluation that constitutes the CI. The rules have been designed to interpret straight-forward, visual observation data in much the same manner that a seasoned engineer would interpret field observations. The experts took many factors into account as they evaluated the CI. These factors included serviceability or performance and subjective safety. The rules continue to evolve.

21. A series of critical measurements are made on each gate leaf to quantify the CI. Experts were asked to interpret these measurements in light of the serviceability and safety of the gate and to assign limiting values to the measurements. Specifically, a series of distresses are identified. Each distress is quantified by a measurement X. For example, anchorage movement is a distress quantified by the relative motion between the steel and the concrete at the steel and concrete interface. Typically, each distress can either be a problem in itself or an indication of a problem. For example, anchorage movement is a problem in itself if it is sufficiently large to impede gate operation; otherwise it can be indicate a safety problem. The individual distress CI is quantified by:

$$CI = 100(0.4)^{X/X_{max}} \tag{1}$$

where X_{max} is some limiting value of X.[3] Figure 13 illustrates the equation and zones from Table 1. Experts have selected X_{max} to be the point at which the gate requires immediate repair or, at least a more detailed inspection and CI evaluation. In other words, it corresponds to a CI of 40 and is a potentially hazardous situation.

[3]Greimann et al. 1990

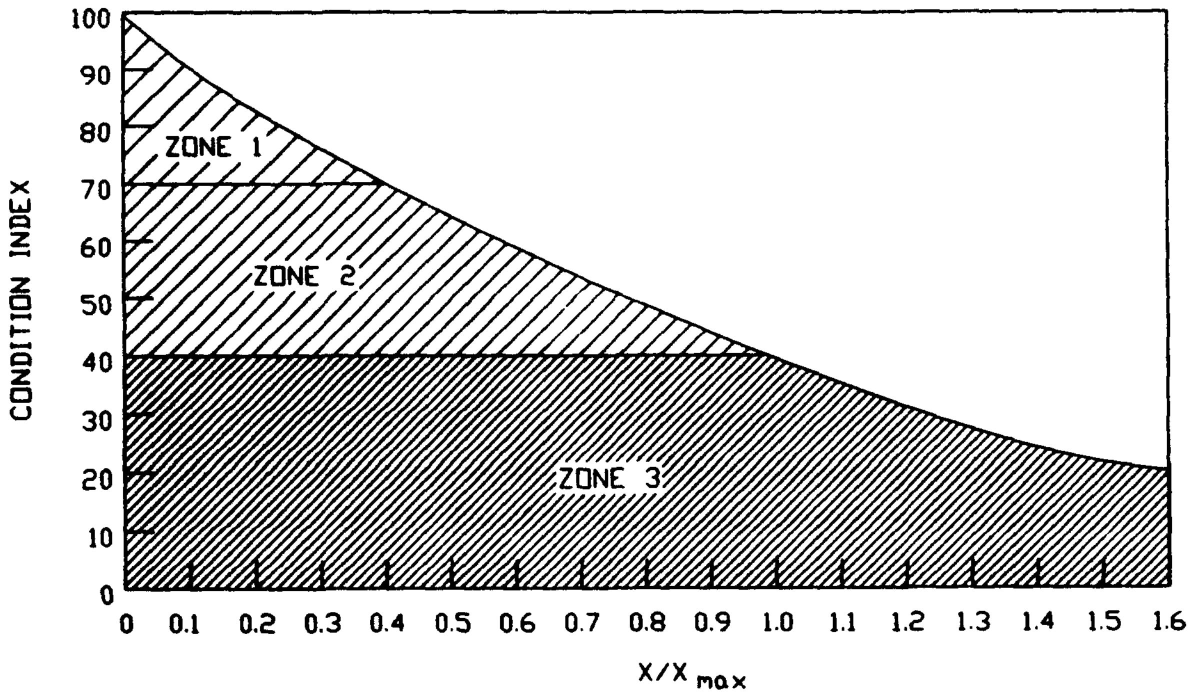


Figure 13. Condition index related to X/X_{max}

Distress Descriptions and X_{max}

22. If a sector gate structure is designed and constructed properly, it has an initial CI of 100. As time passes and the structure is exposed to varying environmental and operational situations, its condition will deteriorate. The CI will degrade as various distresses are incurred. A total of 10 distresses have been identified for categorization in this project. Each is described briefly in Table 3. Each of these distresses can detract from the safety and serviceability of sector gates.

23. The CI for each distress depends upon the ratio of a field measurement X to some limit X_{max} as shown in Eq (1). In the following sections, the definition and measurement of X and X_{max} values for each distress will be described. Values are presented here for consideration by the initial users of this work.

24. Potential causes of each distress are also listed and discussed. These causes are the problems that must be addressed in the maintenance and repair of the gate. Diagnosing causes for each distress is a complex issue. Many times a distress may have several possible causes, and often a combination of distresses must be present before a certain cause can be identified.

Top Anchorage Movement

Definition and Causes

25. Anchorage movement is a parallel and perpendicular displacement of the embedded anchorage system. Movement can occur during opening or closing of the gates and during filling or emptying of the lock chamber. Some anchorage configurations, called flexible anchorage systems, are designed to permit movement, while rigid anchorage systems do not. Anchorage movement can be caused by several factors:

- Corrosion
- Concrete cracks
- Steel elongation or movement
- Additional load
- Movement at shims or nuts.

The top anchorage system is the only mechanism that connects the top of the gate to the concrete wall. Hence, the presence of anchorage movement may indicate a significant structural problem, or it could eventually introduce structural problems into other gate components.

Measurement and Limits

26. For lock gates, measurement of the anchorage movement will be made between the concrete interface and hinge casting bracket (Figure 9) while gates are open (O), closed (C), closed with full head (CF), and jacked (J). (Refer to Section II, Field Inspection, for discussions on gate leaf jacking). For flood gates, the closed full head position is omitted. The maximum motion that occurs at the embedded steel, X, is found by subtracting the smallest of the measurements from the largest in both the parallel and perpendicular directions. Although the position at which the maximum motion occurs is not explicitly contained in the CI calculation, an experienced engineer may wish to know it to help diagnose the particular cause. If jacking is not performed during the current inspection, the largest movement of a previous jacked inspection will be compared to the current measurements and the maximum selected. If jacking has never been performed on a set of gate leaves, the CI for anchorage movement and the combined gate CI cannot be computed. The presence of cracked or spalled concrete at the concrete interface (Figure 10) and the existence of level 3 or greater corrosion on the anchorage configuration is also recorded.

27. For rigid and frame-type anchorage systems, a displacement of 0.03 in. has been selected as the limiting motion.

$$X_{max} = 0.03 \text{ in.} \qquad (2)$$

The experts judged that motion greater than this could indicate a significant structural problem. For flexible anchorage systems (Figure 10), the maximum elastic motion has been selected as:

$$X_{max} = 0.0006\ (L)\ in. \qquad (3)$$

where L is the length of embedded anchorage in inches. Any spalling or cracking of the concrete in this area will reduce the condition index in this area by a factor of 0.85. In addition, a corroded anchorage configuration will reduce the condition index by a factor of 0.85 (Greimann, Stecker, and Rens 1990).

28. The CI for a gate anchorage arm is determined from Eq (1).

Example 1: Suppose that jacking was a part of this inspection. From measurements at the four gate positions, a sector gate leaf has the following maximum movement:

$$X = 0.033\ in.$$

For a rigid anchorage system, the maximum movement is:

$$X_{max} = 0.030\ in.$$

It was determined that the anchorage was corroded at a level 3. The CI for anchorage movement is:

$$CI = [100(0.4)^{0.033/0.030}]0.85 = 31$$

where the 0.85 factor has been used because cracked concrete has been observed.

Example 2: Suppose jacking is not performed during this inspection, but jacking was done on a previous inspection. From measurements at the three gate leaf positions, a sector gate leaf has the following maximum movement:

$$X = 0.018\ in.$$

From the previous jacked inspection, the maximum movement at the four leaf positions was:

$$X = 0.022\ in.$$

The X measurement for the current inspection then would be:

$$X = Maximum(\ 0.022,\ 0.018) = 0.022\ in.$$

The flexible anchorage embedment length is 12 ft. From Eq (3):

$$X_{max} = 0.0006\ (144) = 0.086\ in.$$

It was determined that the anchorage was corroded at a level 3. The CI for anchorage movement is:

$$CI = [100(0.4)^{0.022/0.086}]0.85 = 67$$

where the 0.85 factor has been used because the anchorage is at level 3 or greater. From Table 1 the CI is rated good; that is, there is some deterioration of the anchorage.

Example 3: Suppose jacking has not been done on this leaf and will not be done during the current inspection. No CI can be calculated.

Gate Leaf Deflection

Definition and Causes

29. The gate leaf deflection distress represents the rotational displacement of the nose before the hinge pin moves during gate leaf closing and opening (Figure 8). Gate leaf deflection can be caused by several factors.

- Normal wear of hinge pin or pintle bushings
- Hinge pin or pintle anchorage problems
- Gate structure problems
- Binding of the hinge pin.

Measurement and Limits

30. Gate leaf deflection will be measured at the nose and recess upon leaf opening (O) and closing (C). The X value for gate deflection is chosen as:

$$X = Maximum\ (X_O,\ X_C) \qquad (4)$$

The limiting value for gate deflection was judged to be more critical for wide gates. Values of 3 in. for wide gates and 2 in. for smaller gates were judged to be appropriate. An equation that reflects this is given by

$$X_{max} = 2\ in.\ (W/40) \qquad (5)$$

where W is the gate leaf width in feet.

Example: The following gate leaf deflections were recorded on a 58-ft-wide gate:

$$X_O = 1/8\ in.$$
$$X_C = 1/4\ in.$$

The X value is:

$$X = maximum\ (1/4,\ 1/8) = 1/4$$

The limiting value for gate leaf deflection is given from Eq (5):

$$X_{max} = 2\ in.\ (58/40) = 2.90\ in.$$

The CI for gate leaf deflection is:

$$CI = 100(0.4)^{0.25/2.90} \approx 92$$

From Table 1, the CI is rated excellent; that is, there are no noticeable defects for gate deflection.

Levelness

Definition and Causes

31. The levelness distress represents the vertical displacement of the gate leaves as they are brought from the recessed position to a closed full head position. A gate leaf that is not level can be caused by several factors:

- Gate out of adjustment
- Hinge pin wear
- Pintle problems.

Although the direction of elevation levelness movement is not calculated, an experienced engineer may wish to know this to help diagnose severity. For example, gate leaves that run uphill from the closed to recessed positions are not a problem because they are generally adjusted in the closed position.

Measurement and Limits

32. For lock gates, measurement of the levelness distress will be made at the nose (N) and recess (R) while the gate is open (O), closed (C), and closed full head (CF). For flood gates, the closed full head position is omitted. The maximum motion is found by subtracting the smallest of the measurements at the gate leaf positions from the largest. The X value for change in nose elevation is given by

$$X_n = Maximum\ absolute\ value\ (X_O - X_C,\ X_O - X_{CF},\ X_C - X_{CF}) \qquad (6)$$

where the X measurements are at the nose. Similarly, the X value for change in recess elevation is:

$$X_r = Maximum\ absolute\ value\ (X_O - X_C,\ X_O - X_{CF},\ X_C - X_{CF}) \qquad (7)$$

where the X measurements are at the recess. The X value for levelness is the largest of Eq (6) and (7). For hanging sector gates, the limiting X_{max} value for nose and recess elevation change is:

$$X_{max} = 0.5\ in. \tag{8}$$

For roller gate leaves, the limiting value is:

$$X_{max} = 0.25\ in. \tag{9}$$

Example: The following elevation readings have been recorded in feet for a hanging sector gate leaf.

Closed Full Head		Closed	Open
Nose	3.82	3.81	3.80
Recess	3.75	3.74	3.75

From Eq (6), the appropriate X value for nose elevation change is:

$$X_n = Maximum\ (3.80\text{-}3.81,\ 3.80\text{-}3.82,\ 3.81\text{-}3.82) = 0.02\ ft$$

From Eq (7), the appropriate X value for the recess elevation change:

$$X_r = Maximum\ (3.75\text{-}3.74,\ 3.75\text{-}3.75,\ 3.75\text{-}3.74) = 0.01\ ft$$

The levelness X value is:

$$X = Maximum\ (0.01,\ 0.02) = 0.02$$

The limiting value for a hanging sector gate leaf is:

$$X_{max} = 0.5\ in. = 0.041\ ft$$

The levelness CI is:

$$CI = 100(0.4)^{0.02/0.041} = 64$$

From Table 1, the levelness CI is rated good.

Cracks

Definition and Causes

33. Cracks usually represent a narrow opening, break, or discontinuity in the structural steel members. Cracks are caused by fatigue, brittle fracture, or overstressed structural steel components, often from barge or vessel impact. Obviously, cracks have significant structural implications, because they can continue to grow if the cause of the overstress still exists or if the remaining steel cross section cannot carry the normal loads.

Measurements and Limits

34. The number of occurrences of cracks in the girders (G), skin (S), or framing (F) will be recorded on the inspection form. Size and location of cracks are also recorded but are not used in the calculation of the CI. It is implicitly assumed that very large cracks do not occur at the time of the inspection. Such cracks would be recognized and repaired immediately because of possible severe consequences. The limiting value for girder cracks is:

$$X_{maxG} = 1 \tag{10}$$

that is, one crack in a girder is considered critical. The limiting value for skin plate and framing cracks, is:

$$X_{maxS} = 10 \tag{11}$$

$$X_{maxF} = 5 \tag{12}$$

35. The skin and framing are highly redundant and can tolerate more cracks with less severe consequences. Failure of an entire skin plate panel would be a big, but not a disastrous problem. The CI for all cracks is taken as the minimum of girder, skin, and framing values:

$$CI = minimum\ (CI_G,\ CI_S,\ CI_F) \tag{13}$$

Example: The following numbers of cracks were counted for a sector gate leaf:

$$X_G = 0$$
$$X_S = 3$$
$$X_F = 1$$

The CI for girder cracks is:

$$CI_G = 100(0.4)^{0/1} = 100$$

The CI for skin plate cracks is:

$$CI_S = 100(0.4)^{3/10} = 76$$

The CI for framing cracks is:

$$CI_F = 100(0.4)^{1/5} = 83$$

The CI for all cracks is:

$$CI = Minimum\ (100,\ 76,\ 83) = 76$$

From Table 1, the CI is rated very good; that is, minor deterioration is evident in the crack distress.

Dents

Definition and Causes

36. Dents represent a disfiguration of the major components of sector gate leaves. Dents can be caused by several factors, most often by barge or vessel impact. Dents, particularly in girders, can cause structural distress and possibly a safety problem. A badly deformed girder cannot safely carry its design load.

Measurements and Limits

37. The number of occurrences of dents on the girders, skin, or framing will be recorded on the inspection form. Size and location of dents are also recorded but are not used in the calculation of the CI. The limiting value for the number of girder dents is:

$$X_{maxG} = 1 \tag{14}$$

The limiting value for the number of skin plate dents is:

$$X_{maxS} = 10 \tag{15}$$

The limiting value for the number of intercostal dents is:

$$X_{maxF} = 5 \tag{16}$$

As with cracks, the CI for all dents is the minimum:

$$CI = Minimum\ (CI_G,\ CI_S,\ CI_F) \tag{17}$$

Example: The following dent data were obtained for a sector gate leaf:

$$X_G = 0$$
$$X_S = 4$$
$$X_F = 1$$

The CI for girder dents is:

$$CI_G = 100(0.4)^{0/1} = 100$$

The CI for skin dents is:

$$CI_S = 100(0.4)^{4/10} = 69$$

The CI for framing dents is:

$$CI_F = 100(0.4)^{1/5} = 83$$

The CI for all dents is:

$$CI = Minimum\ (100,\ 69,\ 83) = 69$$

From Table 1, the dent CI is rated good.

Noise, Jumping, and Vibration (NSV)

Definition and Causes

38. Noise, jumping, and vibration distress represents abnormal gate sounds during the opening and closing of the gate leaf. Gate noises and vibration are caused by several factors:

- Seizing of pintle
- Poorly lubricated pintle system
- Water passing through or around gate
- Seals rubbing on sill
- Gate out of adjustment.

Although a noise is often difficult to isolate and diagnose, abnormal noises should not be ignored because they commonly indicate a problem. Normal noises, jumping, and vibration include those caused by seals or operating machinery.

Measurement and Limits

39. Noise is recorded when it occurs at a specific location as the gate leaves are opened or closed. The presence of vibration and jumping at any point in the gate leaf swing is also recorded. Noise, jumping, and vibration that occur when the leaf is over 90 percent closed or over 10 percent recessed

are not used to reduce the CI because several routine or normal noises occur at or near the fully closed or fully open positions. In addition, normal noise, jumping, and vibration occurrences, such as those caused by the operating machinery or gate leaf seals, are also not used to reduce the CI. Between the 10 percent and 90 percent closed positions, any abnormal noise, jumping, and vibration will affect the CI. The CI for the possible combinations follow:

Noise, Vibration, or Jumping	CI
None	100
Yes for any of the three	70
Yes for any two	40
Yes for all three	30

Obviously, this distress is more subjective and less quantifiable than the other distresses; however, its importance should not be minimized because abnormal noises almost always indicate abnormal behavior that should be investigated.

Example: As a sector gate leaf was brought into the recessed position, it made a popping noise at 75 percent closure. Also, a squealing noise due to the gate seals occurred throughout the gate operation. The CI is:

$$CI = 70$$

because the gate leaf seal noise is normal and is ignored in determining the CI. If the noise had not been due to the seals, the CI would have been 40. From Table 1, this CI is rated very good.

Corrosion

Definition and Causes

40. Corrosion is the loss of the steel material in a sector gate leaf due to interaction with its environment. The rate of corrosion depends on the concentration of moisture in contact with the steel. A sector gate structure is exposed to different areas of corrosion. While corrosion is usually very evident and easily noticed in the exposed areas, it is often the concealed components, that is, those below the water surface, that are of most concern for safety reasons. Most light corrosion has little structural significance. However, extensive corrosion can sufficiently reduce the steel cross-sectional area so that stresses are significantly increased. Corrosion of a girder is more critical than skin corrosion just as girder cracks are more important than skin cracks.

Measurement and Limits

41. The effect of corrosion in the atmospheric and splash zones is used to evaluate the corrosion CI because it is visible there. A distress coefficient for corrosion must take into account that corrosion of a sector gate structure seldom impedes the operation of the structure but does reduce its safety. The effect is a subjective evaluation of safety that is difficult to quantify by measurements or simple testing. One way to evaluate the corrosion of a structure is to set a series of standards or levels of corrosion having corresponding numeric distress coefficients. The basis for such an evaluation standard would be new steel or clean and painted structural steel with no scale or pitting. Table 2 describes corrosion levels, and the associated photographs in Figure 12 illustrate the various levels of corrosion that are used in the evaluation of the corrosion CI. The corrosion levels of the girders (G), upstream and downstream skin (S), and framing (F) will be recorded on the inspection form. The corrosion levels represent the X values.

42. The limiting values for girder corrosion, X_{maxG}, skin corrosion, X_{maxS}, and framing corrosion, X_{maxF}, are:

$$X_{maxG} = 3 \tag{18}$$

$$X_{maxS} = 4 \tag{19}$$

$$X_{maxF} = 4 \tag{20}$$

As noted above, girder corrosion has more significance than skin corrosion because of the critical structural nature of the girders.

43. The CI for skin corrosion will be the minimum of the downstream (D) and the upstream (U) corrosion CIs. Girder and framing corrosion CIs are taken at the worst location. The corrosion CI for a leaf is the minimum:

$$CI = Minimum\ (CI_G,\ CI_S,\ CI_F) \tag{21}$$

Example: A sector gate leaf has the following corrosion levels recorded:

Girder:	$X_G = 2$	
Skin:	$X_{US} = 1$	$X_{DS} = 2$
Framing:	$X_F = 1$	

The CI for skin corrosion is:

$$CI_{US} = 100(0.4)^{1/4} = 80$$
$$CI_{DS} = 100(0.4)^{2/4} = 63$$
$$CI_S = Minimum\ (63,\ 80) = 63$$

The CI for girders is:

$$CI_G = 100(0.4)^{2/3} = 54$$

The CI for framing is:

$$CI_F = 100(0.4)^{1/4} = 80$$

The CI of the entire corrosion over the gate leaf is:

$$CI = \text{Minimum } (63,\ 54,\ 80) = 54$$

From Table 1, the corrosion CI is fair; that is, there is moderate deterioration.

Hinge Wear

Definition and Causes

44. Hinge wear is the total amount of wear in the hinge pin casting and bushing. Typically, each gate has a similar two-piece anchorage configuration: a hinge bracket casting on the gate and a bracket attached to the embedment assembly (Figure 11). Hinge wear can be caused by several factors:

- Normal use and wear over time
- Abnormal wear due to lubrication problems
- Abnormal wear due to additional loads
- Creep failure of bushing materials.

Measurement and Limits

45. Initially, the reference hinge wear will be measured as the relative movement between the hinge bracket and hinge bushing from the hanging to the jacked position. After the reference wear has been determined, measurement can be made at the current time by measuring between the permanent reference points with the gate half open in the hanging position (Figure 11). The current hinge wear is the difference between the current hanging dimension and the jacked reference dimension. The jacking measurement should be made during the first inspection. If the bushing and pin are new, the jacked measurement will equal the hanging dimension, which will be the distance between the reference points. If jacking has never been performed on a set of gate leaves, the CI for hinge wear and the combined gate CI cannot be computed.

46. A displacement of 0.375 in. has been selected as the limiting value for hinge wear.

$$X_{max} = 0.375 \text{ in.} \tag{22}$$

Example: The reference dimension determined by jacking a sector gate was determined to be 4.25 in. At the current time, the distance between the reference points is 4.55 in. The X value for this distress is:

$$X = 4.55 - 4.25 = 0.30 \text{ in.}$$

The CI for hinge wear is:

$$CI = 100(0.4)^{0.3/0.375} = 48$$

This number signifies a fair condition where the function is still adequate but repair may be required in the near future.

Incremental Wear of the Thrust Bushing From Reference Position

Definition and Causes

47. Incremental wear of the thrust bushing is measured by a vertical elevation change at the vertex from a baseline reference elevation. Wear on the thrust bushing or pintle is caused by several factors:

- Normal use wear over time
- Abnormal wear due to lubrication problems
- Abnormal wear due to additional loads
- Creep failure of bushing materials.

Measurement and Limits

48. The CI for incremental wear of the thrust bushing depends on measurements made during subsequent inspections. At the first inspection, the reference vertex elevation is established as the maximum difference between the vertex and reference rod readings while the gate leaves are in several different positions. On subsequent inspections, the current vertex elevation is established in a similar manner. The incremental wear is determined by subtracting the current vertex elevation from the reference vertex elevation.

49. A displacement of 0.25 in. has been determined as the limiting value for the incremental vertex elevation change:

$$X_{max} = 0.25 \text{ in.} \tag{24}$$

Total thrust bushing wear can generally exceed this value significantly. The lower value of 0.25 in. was selected recognizing that only incremental wear is being measured.

Example: The initial reference vertex elevation was determined to be -2.350 ft. At the current time the vertex elevation was measured to be -2.365 ft. The X value for this distress is:

$$X = -2.350 - (-2.365) = 0.015 \text{ ft}$$

The CI for thrust bushing wear is:

$$CI = 100(0.4)^{0.015/0.021} = 52$$

This number indicates a fair condition with moderate incremental deterioration.

Leaks and Boils

Definition and Causes

50. The leak distress represents water passing through or around the gate leaves. Several kinds of skin and seal leaks or boils can be tolerated because they usually do not present a significant structural problem. For example, nose leaks may indicate seal wear or deterioration, or it could represent an improper gate setting. Although the leaks may be troublesome, they do not necessarily indicate a safety risk. Leaks and boils are caused by several factors:

- Corrosion
- Structural cracks
- Vessel impact
- Blockage at the sill
- Improper gate alignment
- Improper adjustment at the anchorage system
- Damaged or missing vertical or bottom seals.

Measurement and Limits

51. The location and area A_S of skin plate leaks are recorded. The X_S value for skin plate leaks is:

$$X_S = \text{Sum of } A_S \qquad (25)$$

The limiting value for fresh water skin plate leaks is:

$$X_{maxS} = 100 \text{ in.}^2 \qquad (26)$$

For salt water, the limiting value for skin plate leaks is:

$$X_{maxS} = 10 \text{ in.}^2 \qquad (27)$$

52. The location and area of nose (A_N) and recess (A_R) leaks are recorded. Leaks due to damaged or missing seals are considered normal maintenance and are omitted in the calculation of the CI, but are recorded on the inspection form. The X_{NR} value for nose and recess leaks is:

$$X_{NR} = A_N + A_R \qquad (28)$$

Similar to skin leaks, the limiting value for fresh water nose and recess leaks is:

$$X_{maxNR} = 100\ in.^2 \tag{29}$$

For salt water, the limiting value for nose and recess leaks is:

$$X_{maxNR} = 10\ in.^2 \tag{30}$$

53. Boils are leaks that occur under water. The occurrence of boils along the sill is recorded. The X value for boils is:

$$X_B = Total\ number\ of\ boils \tag{31}$$

The limiting value of fresh water boils is:

$$X_{maxB} = 2 \tag{32}$$

The limiting value of salt water boils is:

$$X_{maxB} = 1 \tag{33}$$

The CI for leaks and boils is the minimum of skin, nose, and recess leaks and boil CIs.

Example: A fresh water sector gate leaf has the following leak data:

Skin:	24 in.^{2}, 12 in.^{2}
Nose:	48 in.^{2}
Recess:	12 in.^{2}
Boil:	1 boil

From Eq (25):

$$X_S = 36\ in.^2$$

The CI for skin leaks is:

$$CI_S = 100(0.4)^{36/100} = 72$$

From Eq (28), the X_{NR} value for leaks is:

$$X_{NR} = 60\ in.^2$$

The CI for nose and recess leaks is:

$$CI_{NR} = 100(0.4)^{60/100} = 58$$

Because one boil occurred, the CI for boils is:

$$CI_B = 100(0.4)^{1/2} = 63$$

The CI for all leaks and boils is:

$$CI = Minimum\ (72,\ 58,\ 63) = 58$$

From Table 1, the CI for leaks and boils is in good condition.

Multiple Distresses

54. When several types of distress occur simultaneously, such as both anchorage movement and cracks, the CIs are combined into a single value. Weighting factors are introduced to reflect the importance of the various distresses. Hence, let w_i be the weighting factor of the CI for distress i (Table 4). The weighting factors assign more value to the more significant distresses. Relative initial weights are listed in Table 4. They reflect, to some degree, the opinion of the Corps experts and also the opinions of the authors. The table illustrates that anchorage movement is the most important and dents the least important. The normalized weighting factors are defined by:

$$W_i = \frac{w_i}{\Sigma w_i}(100) \tag{34}$$

where

$$\Sigma W_i = 100 \tag{35}$$

These normalized values are listed in Table 4 (rounded to add up to 100). The combined CI for all distresses is then given by:

$$CI = W_1CI_1 + W_2CI_2 + \ldots.\ W_{10}CI_{10} \tag{36}$$

where the sum is for all 10 distresses.

55. During the field testing of a preliminary version of the above rating procedure, it became clear that as a distress became more severe, its relative importance became larger. To account for this, a variable adjustment factor was introduced to increase the distress weighting factor w as its CI

approached Zone 3. The adjustment factor plotted in Figure 14 has a maximum value of eight; that is, if a distress has a CI less than 40, its importance increases eight times.

Field Testing

56. The performance of the rating rules was evaluated by comparing the calculated CI values to the subjective CI values determined by a group of sector gate expert engineers. The expert engineers provided the guidance for establishing distress rule values and observation ratings at a field test of the sector gates. In March 1990, preliminary discussions and rule development were initialized in Galveston, TX and New Orleans, LA. Further enhancements were made in October 1990 during meetings in New Orleans and Clewiston, FL. The sector gate experts who participated in the initial rule development were Harold Trahan and Water Theal (New Orleans District) and Jerry Dean (Jacksonville District).

57. The inspection and rating procedure has been applied in seven field tests (see Tables 5 and 6). In March 1991 three preliminary tests were applied to the following locks in the New Orleans district: Leland Bowman lock, Bayou Boeff lock, and Algiers lock. Local lock personnel and Corps experts Dean and Trahan were involved in this testing. Dr. Anthony Kao (USACERL project monitor) and David McKay (USACERL) were observers. The results of these field tests, although primarily qualitative in nature, were used to make several modifications to the initial version of the rating procedure.

58. In July 1991 the remaining four field tests were conducted in the Jacksonville Florida district (Tables 5 and 6). Nine Corps experts were involved: Jerry Dean, Steve Schneider, Joe Britton, Jim Finney, Russ Burkett, Manny De Jesus, and Larry Mason were present from Jacksonville as well as Harold Trahan and Alan Matherne from New Orleans. Kao and McKay were also present. Four different locks were inspected: Ortona, W.P. Franklin, St. Lucie, and Port Mayaca. The results of these field tests were used to make minor modifications and to calibrate the rating system. Each expert was asked to rate the individual distresses in each gate leaf, that is, assign a CI to each distress. Additionally, the experts were asked to assess an overall leaf CI. Many of the comments and suggestions made during that test have been incorporated into the current version of the procedure. Some adjustments to X_{max} values and weighting values were made to better fit the experts' ratings. The previous portions of Part III include these changes.

59. The following graphs (Figures 14 through 24) present the expert subjective index versus the calculated CI for the 10 distresses on each of the gate leaves in the field tests. One graph is presented for each distress.

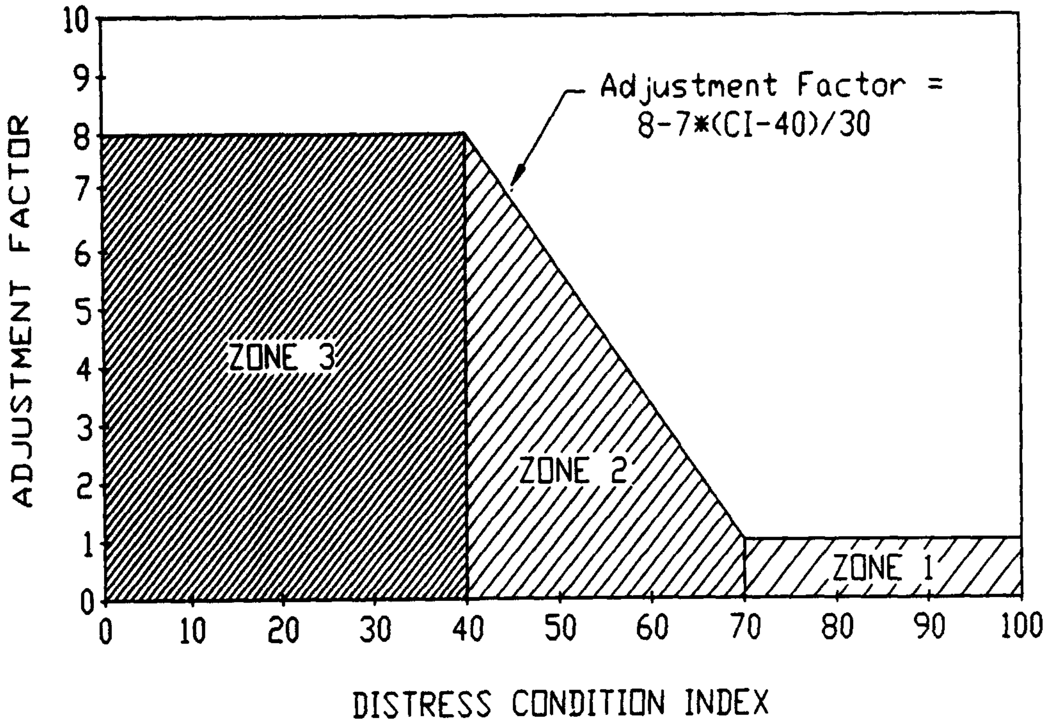


Figure 14. Weight adjustment factor for condition index

Each graph contains eight groups of data, one group for each of the gate leaves. The following abbreviations are used in each of the graphs:

FRANK R	= W. P. Franklin Lock, upper right gate leaf
FRANK L	= W. P. Franklin Lock, upper left gate leaf
ORTONA R	= Ortona Lock, lower right gate leaf
ORTONA L	= Ortona Lock, lower left gate leaf
MAYACA R	= Port Mayaca Lock, lower right gate leaf
MAYACA L	= Port Mayaca Lock, lower left gate leaf
LUCIE R	= St. Lucie Lock, lower right gate leaf
LUCIE L	= St. Lucie Lock, lower left gate leaf.

Within each group of data are four columns of data that represent:

- highest index assigned by an expert
- lowest index assigned by an expert
- expert average (omitting high and low)
- calculated CI (Part III rules).

An analysis of the comparison of expert rating versus the calculated values for each distress and the overall gate leaf index follow.

Anchorage Movement, Figure 15: The calculated CI for three of the eight gate leaves closely approximates the expert average. The calculated CIs are 10 to 15 points lower than the expert average for the remaining gate leaves. The left gate at Port Mayaca is 30 points lower than the right gate. The field measurements indicated that the hinge bracket casting was deflecting. The experts apparently did not take this into much

account in their subjective rating. The local office is monitoring this situation.

Gate Deflection, Figure 16: The calculated CIs of all eight of the gate leaves closely approximate the expert average.

Leaks and Boils, Figure 17: The calculated CI for four of the eight gate leaves closely approximate the expert average. On Ortona lock, a significant amount of leakage was present, causing the calculated CIs to fall into the mid to upper region of Zone 2. The experts felt the leakage was not critical and put their average CI up into the middle of Zone 1. On the other hand, little or no leakage was present at St. Lucie. The experts rated these gates 15 points lower than the model partially because they felt no distress CI can be 100 if the structure is not new.

Noise, Jump, and Vibration, Figure 18: The calculated CIs for seven of the eight gate leaves closely approximate the expert average. In each of these cases the experts' ratings were 10 to 15 points lower than the calculated ratings because even though there were no identifiable occurrences of noise, jumping, or vibration, the experts again felt no distress can be 100. The left gate leaf at Ortona was shown to have noise due to seal vibration. Since this is considered normal, it was omitted in the inspection. However, the experts apparently took this noise into consideration, somewhat contradicting their rule in Part III.

Hinge Wear, Figure 19: The calculated CI depends on the gate leaves being jacked for the initial inspection. Since this procedure requires a dewatered lock chamber, calculated CI values are not available. Each of the expert averages put all eight gates in the middle of Zone 1.

Incremental Wear on Thrust Bushing, Figure 20: The CI for thrust bushing wear is dependent on subsequent sector gate inspections. Since this procedure requires two inspections at different times, calculated CI values are not available. Each of the expert averages put all eight gates in the middle of Zone 1.

Dents, Figure 21: The calculated CIs of six of the eight gate leaves closely approximate the expert average. The experts rated the left leaves at Ortona and St. Lucie 15 points lower than the model because they felt no distress can be 100.

Levelness, Figure 22: The calculated CIs of all eight of the gate leaves closely approximate the expert average.

Cracks, Figure 23: The calculated CIs of all eight gate leaves closely approximate the expert average. In each of these cases the experts' ratings were again 10 to 15 points lower than the calculated ratings. The authors will verify with the experts if further adjustment of a basic distress for cracks may be required. For example, a beginning index for cracks may be set at 85 or 90 because the experts know there

are actually cracks present, but not visible. They show up under detailed inspection after sand-blasting the gate leaves clean in a dewatered condition.

Corrosion, Figure 24: The calculated CI values on seven of the eight gate leaves correspond well with the expert average. At the left gate of Port Mayaca, one small area of level 2 corrosion caused the CI to fall to 54. This conservative evaluation will highlight the corrosion problem and a subsequent investigation may be in order.

Overall Ratings, All Gates, Figure 25: The overall gate rating by the calculated model tended to track very consistently with the expert average. The experts average distress CIs were used in cases where jacking was required, namely hinge wear and thrust bushing wear). Seven of the eight gate leaves were within 5 points. In one case, the Mayaca left gate, the difference was approximately 10 points. The lower rating by the computer model is directly attributable to the low rating of corrosion and anchorage movement. These individual ratings lowered the combined index rating as well. The authors believe that the computer model reasonably corresponds with the experts' judgement on all eight gate leaves. The rules are ready for initial implementation. The rules will, of course, continue to evolve as new information is obtained and inspection techniques improve.

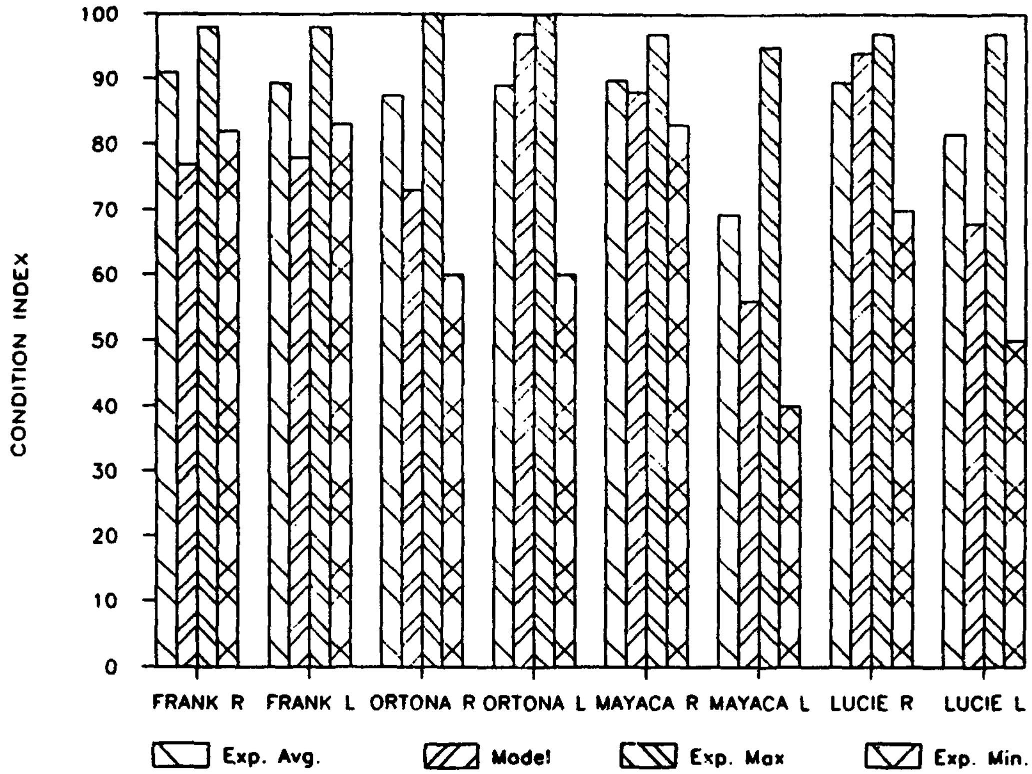


Figure 15. Sector gate rating analysis: Anchorage movement

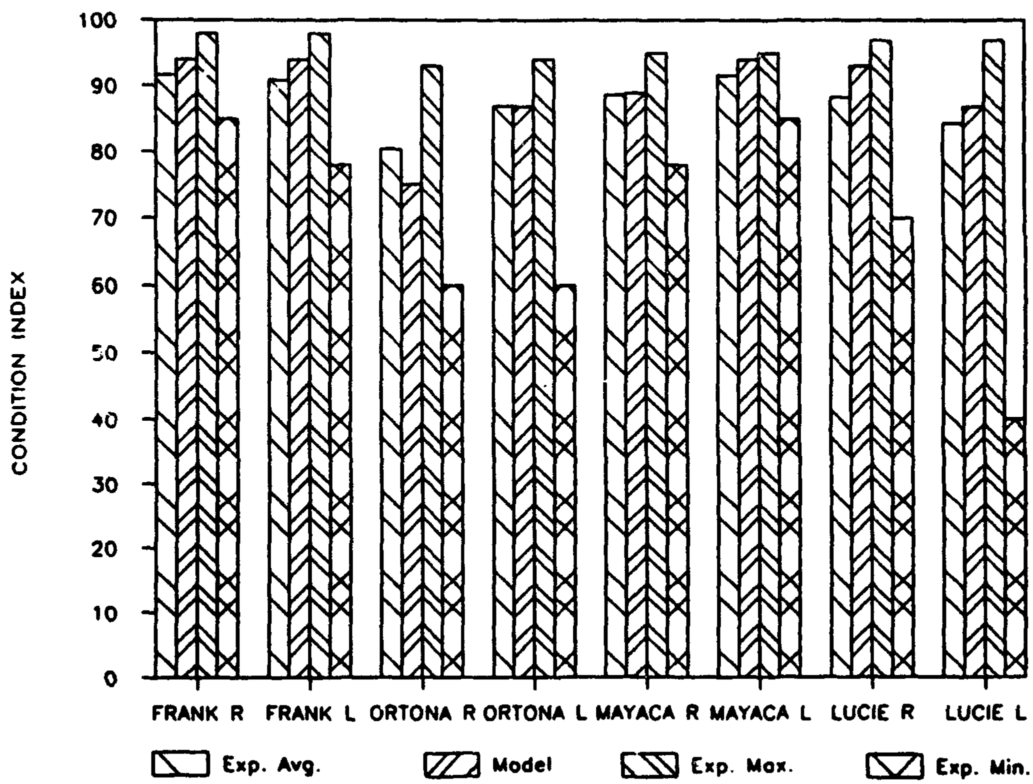


Figure 16. Sector gate rating analysis: Gate deflection

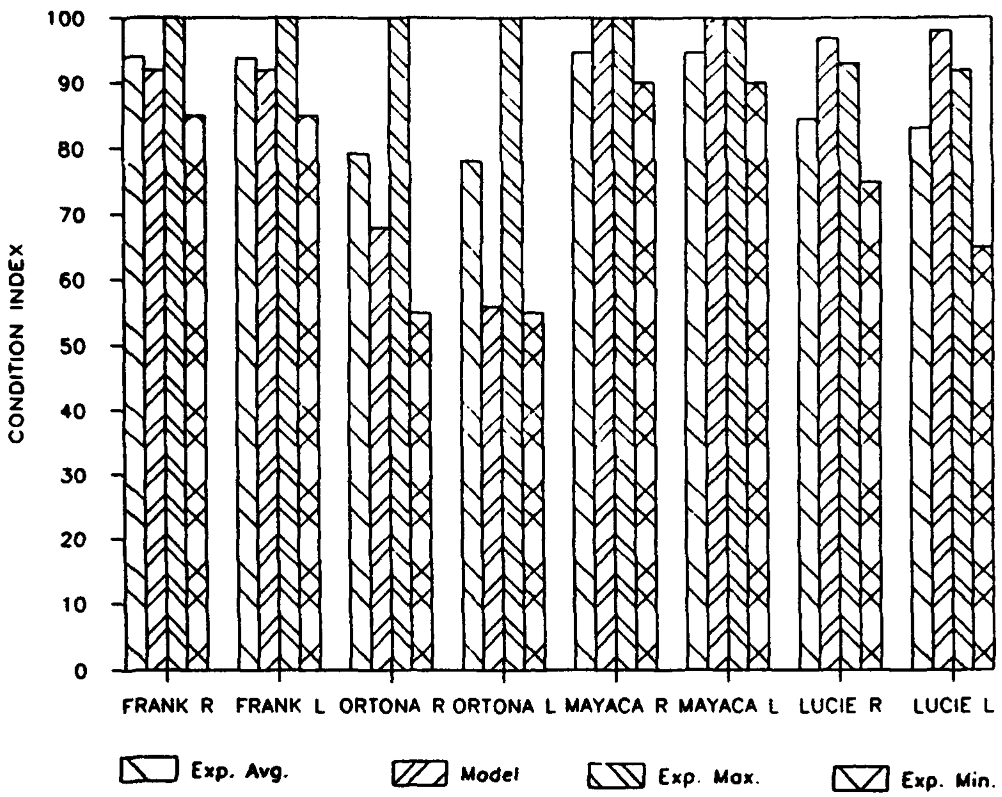


Figure 17. Sector gate rating analysis: Leaks and boils

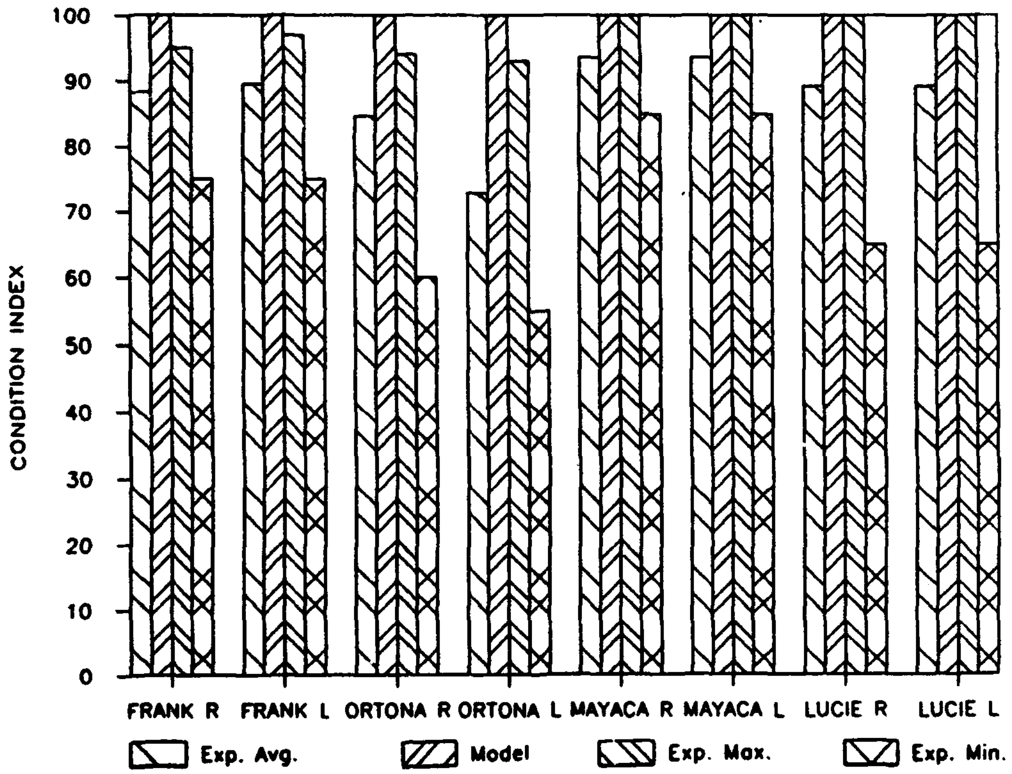


Figure 18. Sector gate rating analysis: Noise, jumping, and vibration

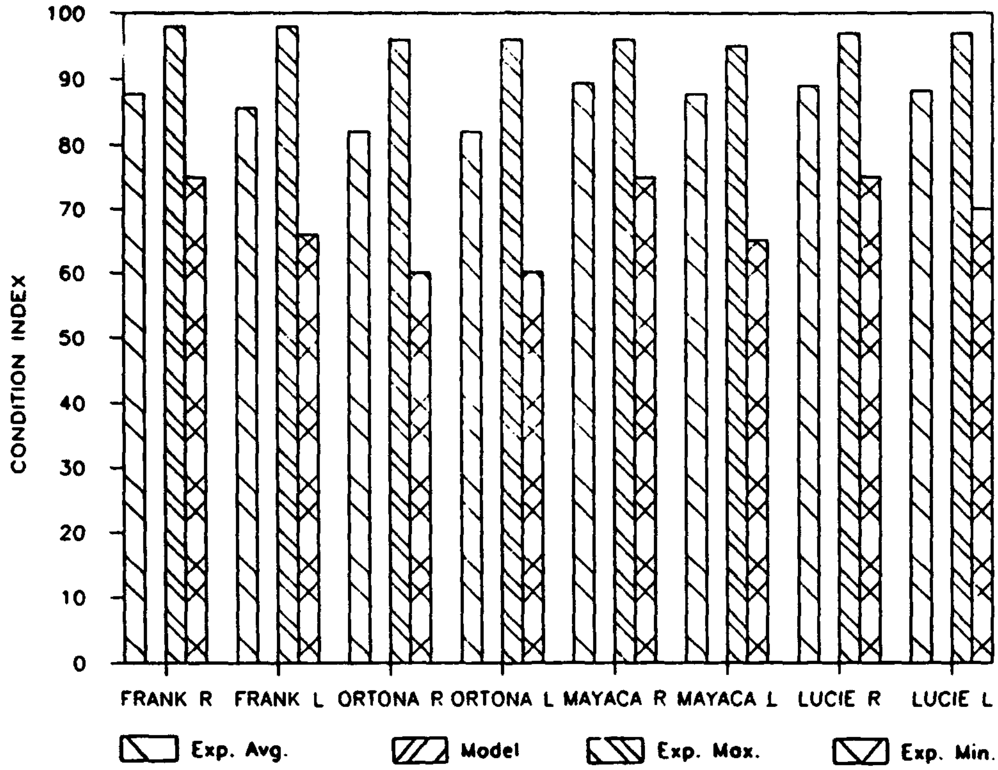


Figure 19. Sector gate rating analysis: Hinge wear

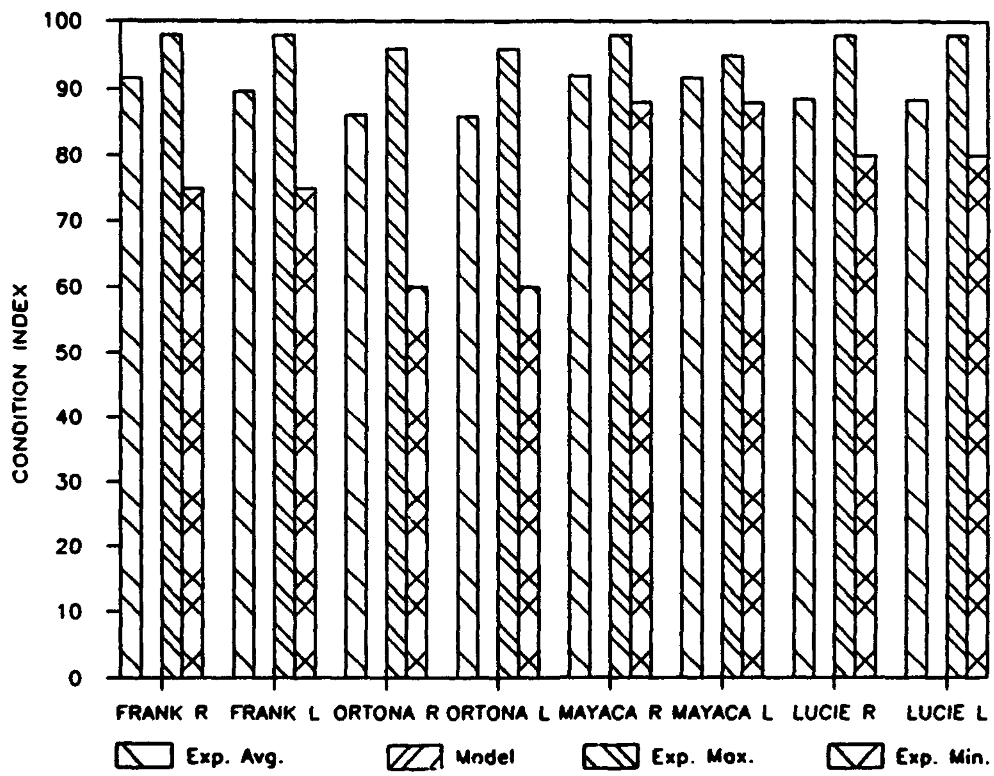


Figure 20. Sector gate rating analysis: Incremental wear on thrust bushing

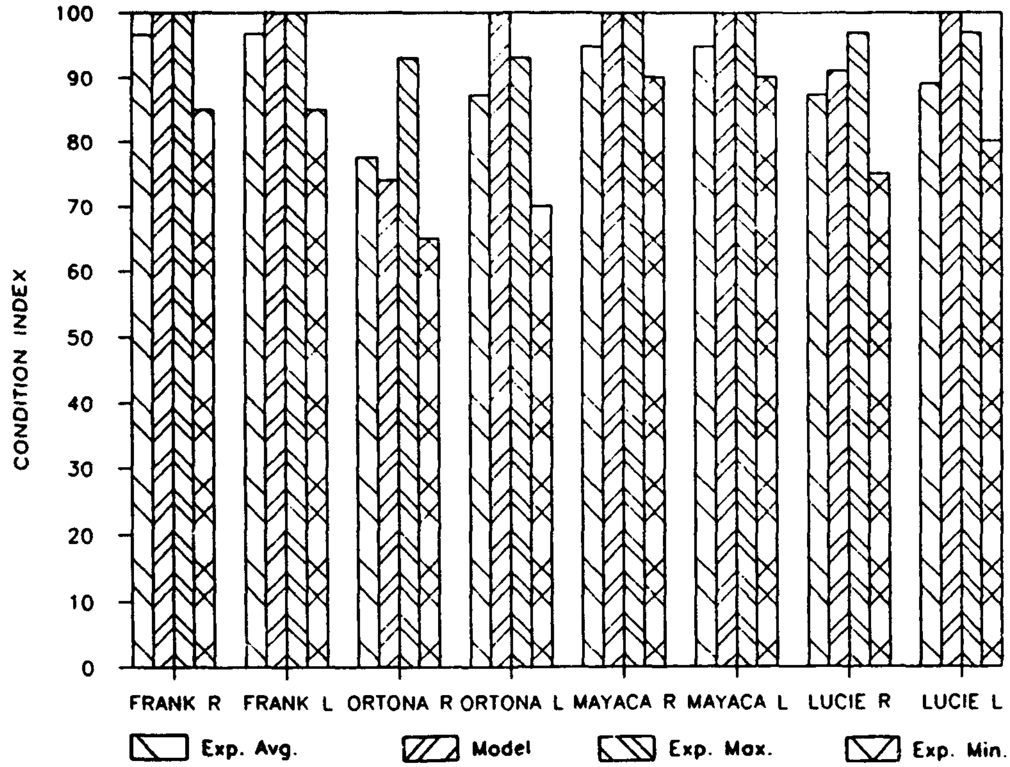


Figure 21. Sector gate rating analysis: Dents

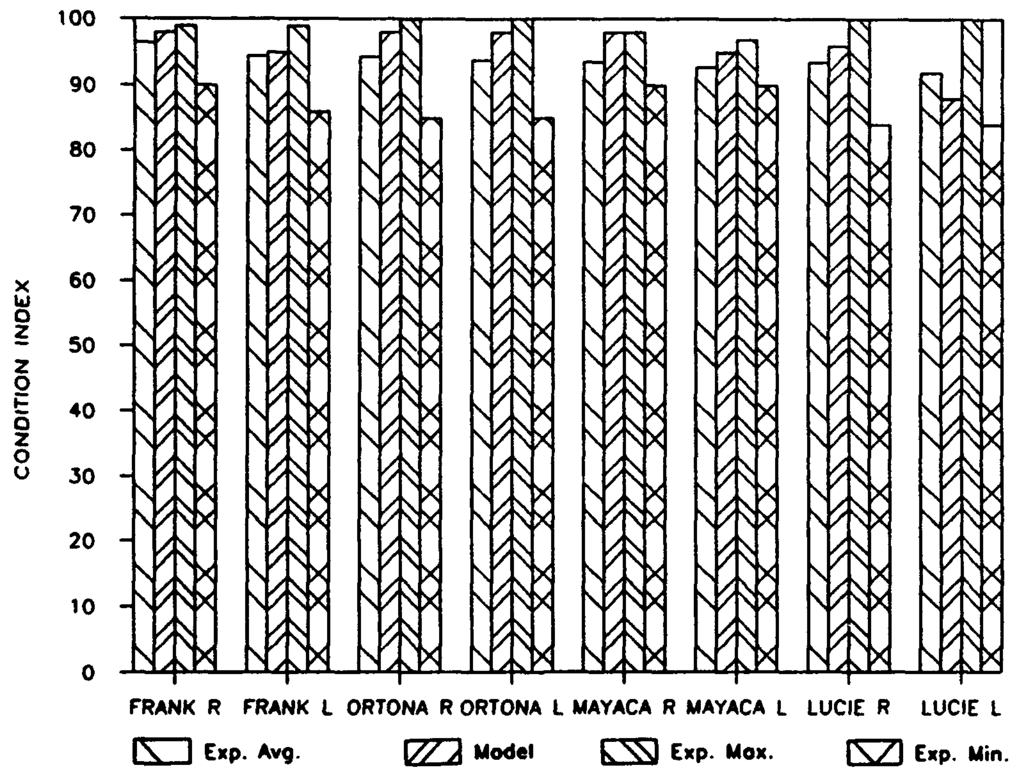


Figure 22. Sector gate rating analysis: Levelness

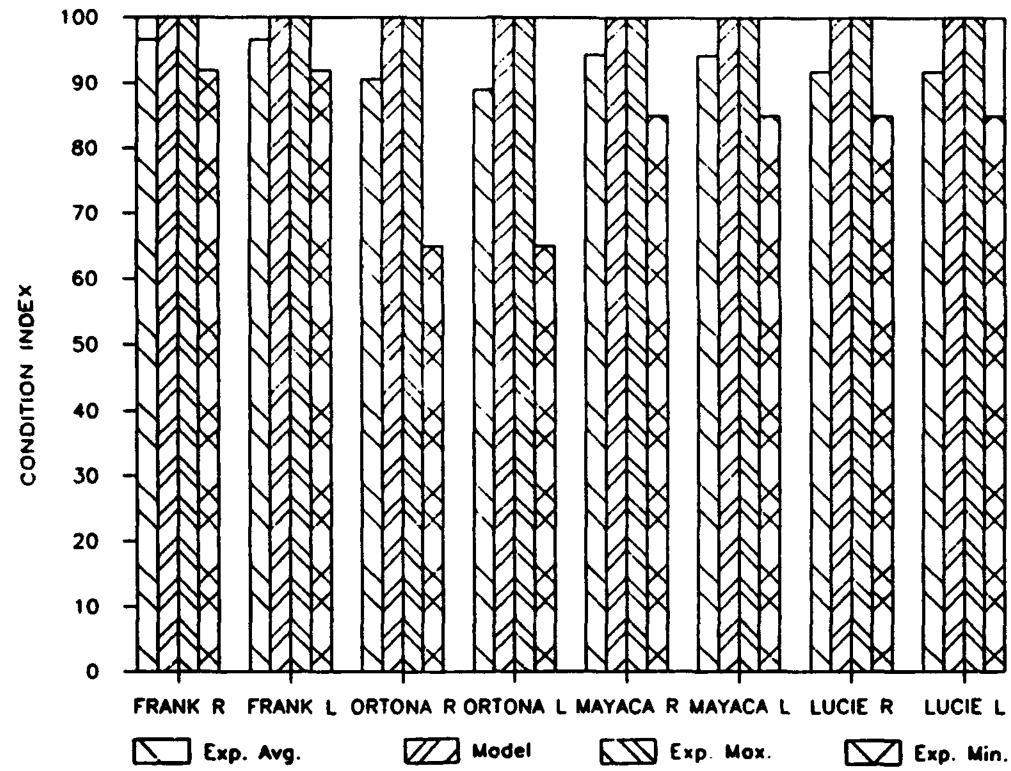


Figure 23. Sector gate rating analysis: Cracks

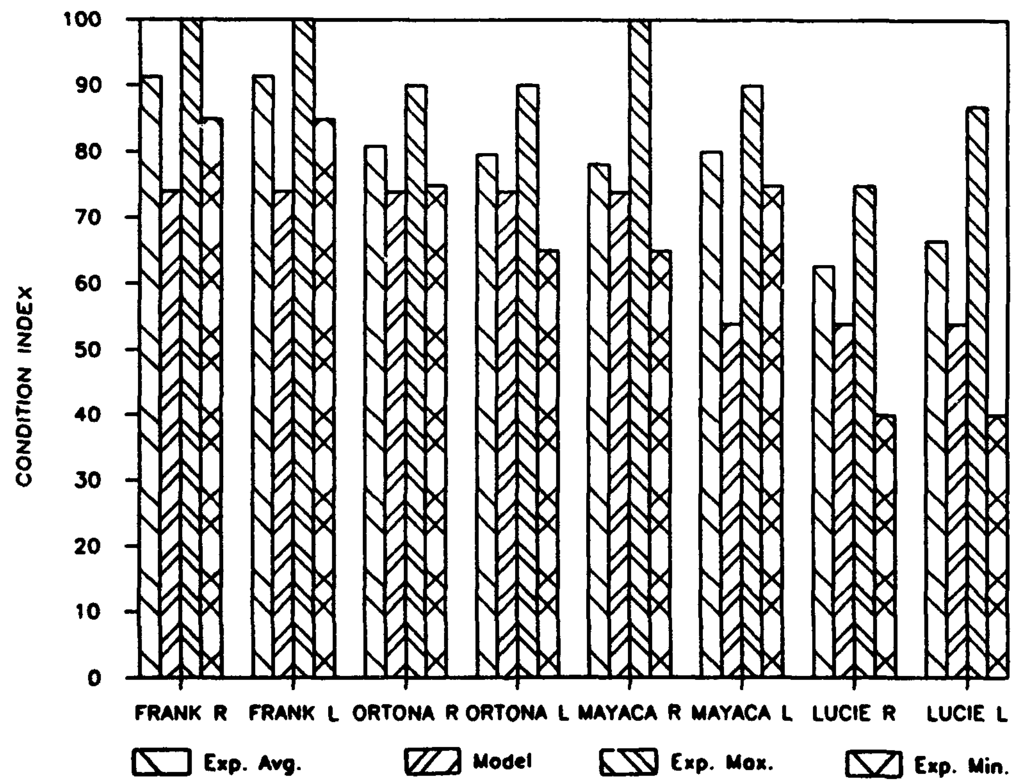


Figure 24. Sector gate rating analysis: Corrosion

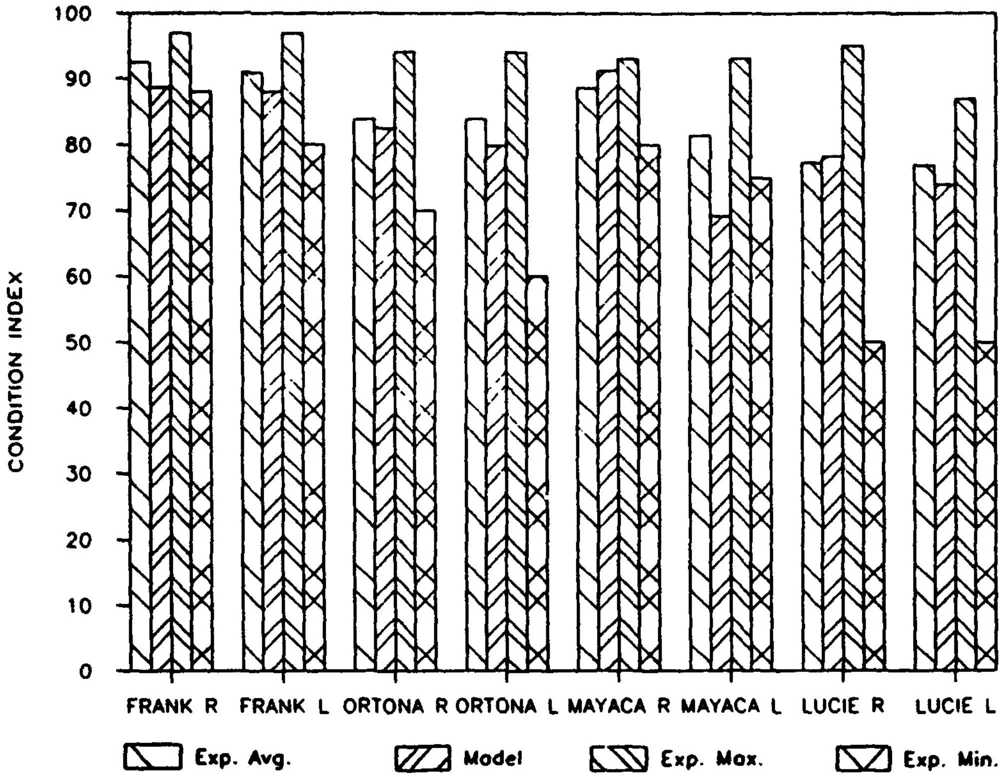


Figure 25. Sector gate rating analysis: Overall ratings for all gates

PART IV: STRUCTURAL CONSIDERATIONS

60. Many factors were taken into account by the experts as they formulated the CI rules. One of the considerations was subjective safety, which refers to the idea that an engineer using his or her judgment may decide that a safety problem is likely. A single observation or series of inspection observations may indicate that the potential for a problem exists or that a safety problem is developing and may soon become critical. These types of observations are difficult to quantify because only visual indications of the problems are present. As an example, excessive movement of the anchorage embedment may indicate a potential safety problem. The embedded anchorage may have corroded and be approaching a failure condition. The only visual observation may be movement at the steel and concrete interface. Only a more detailed inspection, which may require concrete removal, will reveal the true cause. Cracks, dents, corrosion, jumping, and elevation changes may also indicate potential safety problems. Deterioration due to these distresses usually are not accounted for in a classical structural analysis.

61. It follows that many structural considerations are embedded in the CI rules in Part III. In addition to functional and operational factors, the experts took structural factors into account when setting limiting values, tolerances, and weight factors. With this in mind, the structural adequacy can be characterized by several of the distress measurements. Some distresses in Table 3 have a more significant impact on safety than others. The structural distress subset is listed in Table 7.

62. An asterisk is indicated on the distress CI calculation if the structural distress measurement exceeds certain bounds:

Level 1 Flag: $55 < CI < 70$
Level 2 Flag: $40 < CI < 55$
Level 3 Flag: $0 < CI < 40$

On the basis of the experts' judgment, the individual distresses are flagged as the CI becomes low. A structural note along with the corresponding measurement will be included in the summary report for potential structural problems that have been flagged. The purpose of the structural notes is to alert the engineer that a potential structural problem may be forming. Values of the measurement X are also included in the notes. For example, for anchorage movement, the three possible notes are:

Level 1 Note: The anchorage movement was measured to be X inches and should be monitored.

Level 2 Note: The anchorage movement was measured to be X inches and could be a problem. Further investigation may be needed.

Level 3 Note: The anchorage movement was measured to be X inches. This is potentially a structural hazard. Further investigation is needed.

PART V: SUMMARY AND RECOMMENDATIONS

63. The inspection and rating procedure described in this report has intentionally been kept as simple as possible. The inspection requires only simple hand tools such as a tape measure, level, dial gauge, and ruler. An inspection form has been developed for recording historical information (location, previous inspections, or repair history, etc.) and distress documentation (anchorage movement, gate deflection, corrosion, etc.).

64. A CI is computed directly from the inspection records. The CI is a numbered scale from 0 to 100 that indicates the current state of the structure. It is primarily a planning tool that indicates the relative need to perform REMR work. CIs below 40 indicate that immediate repair is required or possibly that a more detailed inspection and analysis is required.

65. A CI based on the subjective opinion of several Corps experts is calculated. It involves at least two considerations: (1) serviceability, or how the structure performs its function on a day-to-day basis, and (2) subjective safety, or how, in the judgment of expert engineers, the safety of the structure has been degraded by various distresses. Structural considerations are flagged on the CI list on the basis of subjective safety. A structural note is generated on the summary report for the structural subset of distresses as the CI decreases.

66. The inspection and rating procedure has been applied in eight tests (March and July 1991). The results of these tests have been incorporated into the current version of the procedure.

67. The current inspection and rating procedure for sector gate structures has had sufficient development and testing to warrant its distribution on a wider basis. However, it should still be considered developmental. Many of the concepts introduced, such as the distress condition index, structural considerations, X_{max} values, and weighting factors should be exposed to a broader range of engineers who work in the area. Modifications to the procedure are certainly expected and suggestions are welcomed.

Table 1

REMR Condition Index Scale

Zone	Condition Index	Condition Description	Recommended Action
1	85 to 100	*Excellent*: No noticeable defects. Some aging or wear may be visible.	Immediate action is not required.
	70 to 84	*Very Good*: Only minor deterioration or defects are evident.	
2	55 to 69	*Good*: Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	*Fair*: Moderate deterioration. Function is still adequate.	
3	25 to 39	*Poor*: Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evalatuion is recommended.
	10 to 24	*Very Poor*: Extensive deterioration. Barely functional.	
	0 to 9	*Failed*: No longer functions. General failure or complete failure of a major structural component.	

Table 2

Corrosion Levels

Level	Description
0	New condition
1	Minor surface scale or widely scattered small pits
2	Considerable surface scale and/or moderate pitting
3	Severe pitting in dense pattern, thickness reduction in local areas
4	Obvious uniform thickness reduction
5	Holes due to thickness reduction

Table 3

Distresses in Sector Gates

Distress	Description
Top Anchorage Movement	Displacement of embedded anchorage system
Gate deflection	Nose deflection before hinge pin rotates
Levelness	Vertical gate displacement
Cracks	Breaks in structural steel components
Dents	Disfigured structural steel components
Noise, jumping, and vibration	Abnormal noise, jumping or vibration during gate operation
Corrosion	Loss of steel due to interaction with the environment
Hinge wear	Total wear in hinge pin casting (anchor bracket to hinge bracket)
Incremental wear of thrust bushing	Vertical wear of thrust bushing from reference position
Leaks and boils	Water passing through or around the gate

Table 4

Unadjusted Weighting Factors for Distresses

Distress	w_i	W_i
Top anchorage movement	10	17
Gate deflection	6	10
Levelness	5	9
Cracks	5	9
Dents	1	2
Noise, jumping, and vibration	5	9
Corrosion	7	12
Hinge wear	8	14
Incremental wear of thrust bushing/pintle	7	12
Leaks and boils	4	6

Table 5

Lock Locations

Lock Name	Year Built	Nearest Town	Waterway
Leland Bowman	1985	Abbyville, LA	Gulf Intercoastal
Bayou Boeff	1954	Morgan City, LA	Gulf Intercoastal
Algiers	1956	New Orleans, LA	Gulf Intercoastal
Ortona	1937	Laballe, FL	Okeechobee
W.P. Franklin	1965	Clewiston, FL	Okeechobee
St. Lucie	1939	Stuart, FL	Okeechobee
Port Mayaca	1979	Pohakee, FL	Okeechobee

Table 6

Lock Dimensions

Lock Name	Gate Size		Chamber Size	
	Height	Width	Length	Width
Leland Bowman	25	70	1200	110
Bayou Boeff	30	40	1200	75
Algiers	30	40	800	75
Ortona	20	32	250	50
W.P. Franklin	28	38	250	56
St. Lucie	35	32	250	50
Port Mayaca	29	38	250	56

Table 7

Structural Distresses

Distress	Brief Description
Top anchorage movement	Embedded steel movement
Jumping	Abnormal gate jumping
Girder cracks	Breaks in main horizontal girders
Girder dents	Disfiguration of main horizontal girders
Girder corrosion	Loss of girder steel
Gate deflection	Nose deflection before hinge pin rotates

APPENDIX A: SUGGESTED INSPECTION PROCEDURE AND SEQUENCE OF LOCKING

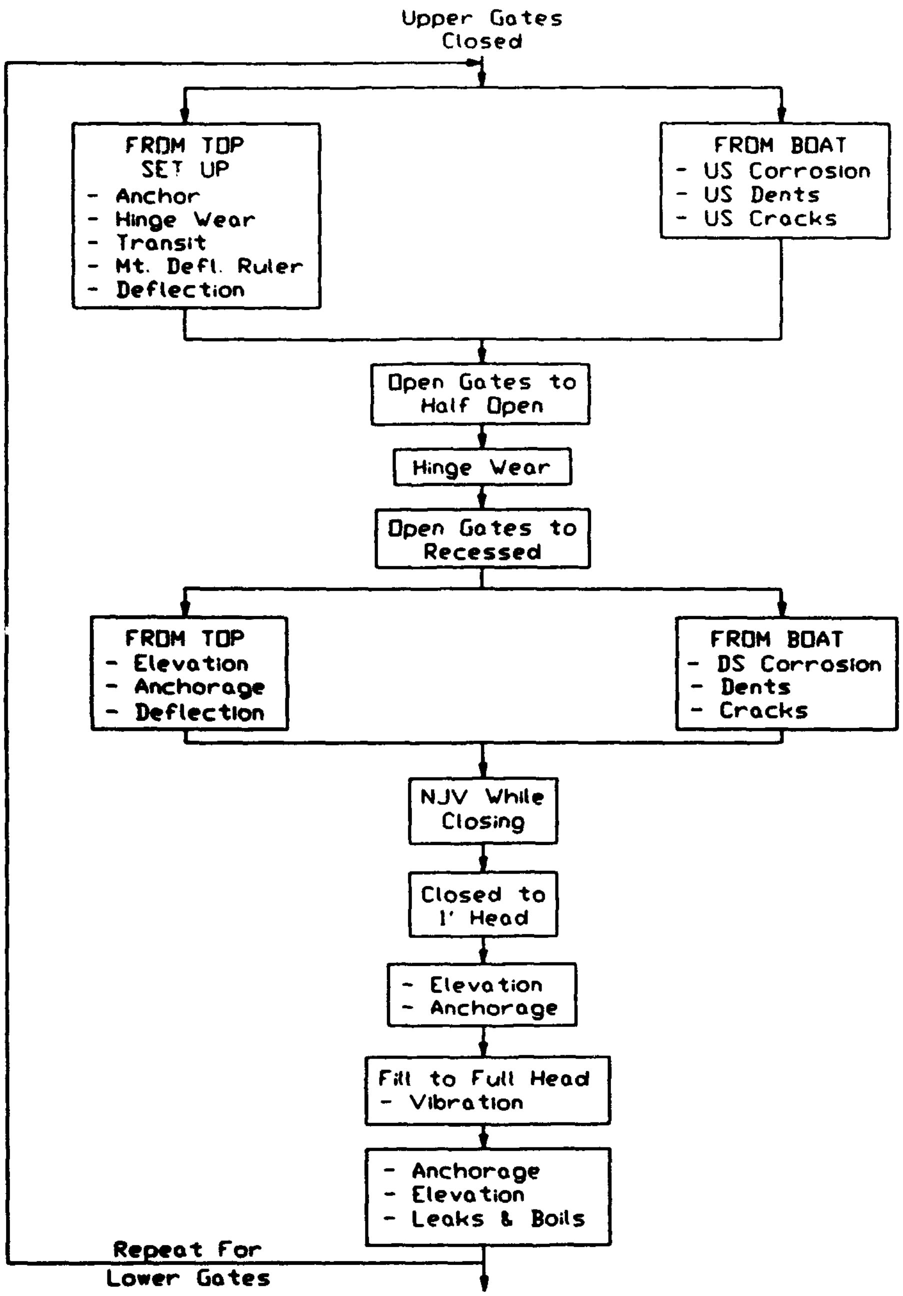


Figure A1. Graphical sequence of inspection and locking procedure

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